My job with the Scottish Manufacturing Advisory Service (SMAS) is as a Lean practitioner. For all intents and purposes, I am an improvement consultant. But I do not just apply Lean methodologies. My technique has evolved from my education, my work experience, and techniques that I have learned from friends, colleagues, and books. One thing I have learned that I want to pass on to you is that virtually all the techniques follow very similar lines. It was this feature that led me to develop my system of blending processes to suit the needs of the client.

The Unloading Process

It came as a surprise, then, when I did a process map for a client, and it showed only two problems. The process was introduced in Chapter 2. It was probably the shortest process I have ever mapped. I cannot describe the actual process for reasons of confidentiality, but I can create a facsimile. The process steps are as follows and are illustrated in Figure 5.1:

1. Deliver the product to the factory.
2. Transfer the materials to the loading area.
3. Transfer the materials into the processing drum. The drum has an output to a conveyor belt, where the quality is checked as the material is transferred.
4. Move the materials by belt into a machine that squashes them into predefined shapes.
5. Sort the bales by content and shape.
6. Store the bales.
7. Sell the bales.
8. Load the bales into vehicles.
9. Ship the bales to the customer.

The two process problems originally seen were variable amounts of contamination from the suppliers of the incoming material and the shaper/baler needing a maintenance schedule. Neither was significant, and yet the process was not running anywhere near as efficiently as it should be. My colleague, Colin Allan, and I stared at the map, looking for inspiration. The team sat silently in anticipation of guidance.

**The Birth of the Capacity Map**

While looking at the map, my mind’s eye overlaid an electronic diagram. It was a basic building block that became the state of the art in electronics in the 1970s, when microchips were being developed. It’s called an *operational amplifier*. For those of you with no electronics knowledge, please don’t be put off at this point. The operational amplifier revolutionized electronics. Early sound amplifiers were complicated circuits with *hundreds* of components. Microelectronics reduced all the components into a single chip about half the size of a thumbnail. The clever bit was that all the user had to do was add a couple of components to feed the electrical “sound” to the amplifier and a component to set the *gain* (how loud the amplifier makes the sound). In the case of an electric guitar amp, for example, all that was needed was a plug socket, a volume dial (unless it was a rock band, where maximum was the only setting used), and an output for wiring to the speakers.

Operational amplifiers are still available 40 years later but are much, much more sophisticated. They still do exactly what the name suggests—amplify the input and make it bigger or louder. We use them to amplify the signal from TV aerials, sound in TVs and sound systems, radios, phones, computers, MP3 players, guitars, and microphones in bands and CD players. In short, we use them for amplifying everything.

So what? Well, the thing about these amplifiers is that they can only amplify sound to the level of the battery that powers them. They all have a maximum output. In the case of sound, they have a maximum volume. This brings us back to the process. If you look at Figure 5.2, you can see the diagram of the amplifier sitting below the process map.
Figure 5.1 The four-input process.
The amplifier has a series of inputs in the same configuration as the process. The main process is not shown as eight steps but rather as one triangle—the shape being completely irrelevant from a practical point of view. The amplifier has a fixed output volume, or capacity, as does the baler, which has a maximum production rate.

In both cases, the output is limited by the operation of the input. In the case of the amplifier, an input dial with fixed gains ($R_1$, $R_2$, or $R_3$, operating like a volume control) limits the output. In the case of the process, it is the way the material is delivered and unloaded that limits the output.

We have all heard about bottlenecks and how they limit production. We also have an appreciation of the theory of constraints, although some of us might not be aware of the technical name. It is best explained in Eli Goldratt’s book, *The Goal*. The capacity map is a simple way to identify process and equipment constraints. It helps us to recognize operations that have limits and those which are limited by the processes around them. For analysis, we will use basic Lean theory and, sometimes, more technical processes such as overall equipment efficiency (OEE).

**The Capacity Map**

If this technique already exists, then I apologize. I do not intend to steal anyone’s idea. As explained earlier, I found my capacity map by necessity. I was looking at the map in Figure 5.1, a really simple process map that had only two red Post-it Notes (problems). Yet I knew that the process was not efficient: It should have been much better. It was just not clear where the losses were coming from.

So, as I stared at the process map, I recognized that the four input options acted like different resistances—constraints—to the process achieving its maximum output. The larger the resistance, the fewer units got out of the process.

Consider a crowd of people passing through a door. The bigger the door, the smaller is the resistance to the flow of people passing through it. This allows more people to pass through in a given time. The size of the door limits its capacity. Another example is the size of a window. A big window lets more light through than a smaller window, so it follows the same argument as the door. Additionally, bad organization can make
Figure 5.2 Comparing the process with the amplifier circuit.

Amplifier output is the ratio of:
- $R_f:R_1$
- $R_f:R_2$
- or $R_f:R_3$
matters worse. If you position something in front of the window, you add to the resistance and reduce the amount of light transmitted even more.

In the process under consideration, the operators reported that the shaper/baler is capable of producing 30 bales in an hour. Initially, I would always accept the value given by the operators, although it is often an underestimate. You can ask the operator later, if required, to get the equipment operation manual and check the specified rate, or you can slowly increase targets as the improvement process becomes established. The figure of 30 bales in an hour would mean that in an eight-hour day, you should get 240 bales from each machine. But the company wasn’t getting anything near that.

Notice that the map is just an evolution of a process map with the production rate at each stage added (Figure 5.3). All we need to do to convert an existing process map into a capacity map is stick on an extra series of Post-its with the current production rates. Better still, we can include the maximum possible production rates, that is, the capacity.

Mark on the Post-it whether it is a specified capacity (from a vendor manual), a best rate achieved, or an estimate based on the usual throughput. In the example, there is only one real capacity limit, and that is the one defined by the equipment manufacturer. The shaper/baler’s Post-it would be marked as a “best-ever rate.” We will assume the capacity of the machine to be true because it was the best throughput the operators claim to have ever achieved. By association, other steps also must be capable of the same rate: checking quality, filling the drum, moving the materials on the conveyor belt, and the rate for storing the bales.

The steps involving people productivity will have upper limits, but they have not been established yet. This is a good point to remind you that making product as fast as possible is not the goal. Making product right the first time at a sustainable rate is the true goal. Time spent correcting mistakes is a part of the process too. Only this waste should be eliminated. When an operator works too fast, mistakes are likely to occur. In addition, the rate probably will drop off as the operator becomes tired. Monitoring the defect rate should pick up this problem.

None of the four inputs is able to generate a production rate higher than the baler capacity, so unless the baler stops operating properly, each input stage is its own bottleneck and defines the process capacity. For fully loaded trucks, the process capacity is 25 bales an hour; it is closer to 20 bales an hour for partially loaded trucks. Transit vans are only capable of delivering 9 bales
Figure 5.3 The capacity map.
an hour. This is an issue owing to the number of loads that are delivered in this way. The fourth line, designed for small volumes, can be as low as 3 bales per hour. This is a special case and does not happen very often.

**Improving the Capacity**

To begin making improvements, we have to investigate what limits the production rates at every stage. The best, consistent rate of 25 bales an hour is achieved only when a full load is delivered. This is running at an acceptable level for the moment. Should we want to improve on this, we would need to speed up rate the trucks pass through the unloading process. This would be a good improvement to make because it also would benefit the others. But it is not the best place to start.

Eighteen wheelers tend to be fully loaded but can be only partially full—from 60 to 80 percent. The transit-sized “white” vans coming from small, local suppliers tend to carry only a quarter of the quantity of an eighteen wheeler. Fortunately, owing to a faster turnaround, they produce a better production rate than the load would suggest. Because they carried such a large proportion of the deliveries, the vans were prioritized for improvement.

Owing to the size and maneuverability of the vans, they can be weighed faster and are able to negotiate the load/unload routes quicker. Even so, a drop in capacity of 64 percent is too much of a loss to be acceptable. When a van is unloaded, output is reduced by 16 bales an hour. To quantify the loss in income (assuming that all units made can be sold), Figure 5.4 illustrates the impact of lost production on income up to the maximum rate of 25 bales in an hour.

At a selling price of $15 (£10) per bale, unloading white vans loses 16 bales or $240 (£160) in one hour. This is $1,920 (£1,280) over an eight-hour shift. At $60 (£40) per bale, we lose $960 (£640) per hour or $7,680 (£5120) per shift. Considering the latter example only, for a five-shift week and 50 weeks in a year, if we only unloaded white vans, we would be losing $1,920,000 (£1,280,000). In reality, we need to know how many white vans we do unload in a year. It could be as high as 25 percent of the throughput. If 25 percent is an accurate rate, we are losing around $480,000 (£320,000). If the bales sold for only $30 (£20) each, the loss would be half this value ($240,000 or £160,000), which is still not to be scoffed at. With accurate data, you can make a better estimate.
Figure 5.4  Sales losses over an eight-hour shift—up to 25 units lost in an hour.
How did the team make improvements? The capacity map made it obvious where the fixes were needed, but it was up to the team to find the solution. What do you think we did?

It was discovered that eighteen wheelers were always waiting to unload materials, and we know that waiting is a waste. So how can we eliminate or reduce the waiting? The ideal solution would be to only unload full trucks and ignore the vans, but we would be losing a lot of business. What is the problem? Trucks can’t get access while a van is unloading. How do we get rid of the vans?

The team brainstormed for ideas. The solution became obvious. Once the capacity issue was recognized and the cause discovered, the solution was to create a second bay for unloading white vans. The bay was designed as a simple unload area—no frills. When a suitable amount was reached, the material was fed to the drum for baling while an empty eighteen wheeler was replaced by the next full truck. Further improvements could be a second drum and conveyor to feed the baler.

The Cabinet Manufacturer

This is a more complex process. There are two lines. The first makes the doors; the second makes the sides, the cabinet bodies, and the internal shelving. The doors can be intricate, with a computer numeric control (CNC) machine ensuring precision. Optional finishes are available, including paint, varnish, and veneers. The final assembly and hardware attachment are done by hand. Equipment has capacities but is often limited by the processes.

So where do we start? The capacity map in Figure 5.5 is an approximation of the process. It does not include all the steps but does contain all the key production rates. Ranges have been included where outputs are variable. The data have been taken from vendor manuals or determined by discussions with the production manager and operators. The discussion also provides a brief summary of the main issues.

This map shows the variation in capacities across the processes. The sanding process (on the calibration sander) has a wide range of throughput. Fitting veneers is a very unreliable process, ranging from 5 to 20 units in an hour. Drying the units after lacquer or painting takes a long time and is limited by space (the units are normally allowed to dry overnight).
Figure 5.5  The cabinet process.
A spreadsheet and a bar graph are also created. Refer to Table 5.1 and Figure 5.6. The spreadsheet helps us see the time taken to produce one unit and the maximum throughput possible for one hour, one shift, and one week.

**Table 5.1  Capacity Data Analysis Table**

<table>
<thead>
<tr>
<th>Process Stage</th>
<th>Time/Job Minutes</th>
<th>Hour</th>
<th>Day (8 hours)</th>
<th>1 Week (40 Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut doors to size—beam saw</td>
<td>2.0</td>
<td>30</td>
<td>240</td>
<td>1200</td>
</tr>
<tr>
<td>Edge bander</td>
<td>4.0</td>
<td>15</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Calibration sander</td>
<td>3.0</td>
<td>20</td>
<td>160</td>
<td>800</td>
</tr>
<tr>
<td>Fit veneers</td>
<td>3.0</td>
<td>20</td>
<td>160</td>
<td>800</td>
</tr>
<tr>
<td>Press veneers</td>
<td>3.0</td>
<td>20</td>
<td>160</td>
<td>800</td>
</tr>
<tr>
<td>CNC (average)</td>
<td>6.0</td>
<td>10</td>
<td>80</td>
<td>400</td>
</tr>
<tr>
<td>Varnish (lacquer)</td>
<td>1.3</td>
<td>45</td>
<td>360</td>
<td>1800</td>
</tr>
<tr>
<td>Paint</td>
<td>4.0</td>
<td>15</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sanding</td>
<td>4.0</td>
<td>15</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Touch up</td>
<td>4.0</td>
<td>15</td>
<td>120</td>
<td>600</td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cabinet panels and shelves</td>
<td>2.0</td>
<td>30</td>
<td>240</td>
<td>1200</td>
</tr>
<tr>
<td>Frames cut to length</td>
<td>1.0</td>
<td>60</td>
<td>480</td>
<td>2400</td>
</tr>
<tr>
<td>Drill mounting holes</td>
<td>1.2</td>
<td>50</td>
<td>400</td>
<td>2000</td>
</tr>
<tr>
<td>Joiners assemble (per man)</td>
<td>12.0</td>
<td>5</td>
<td>40</td>
<td>200</td>
</tr>
</tbody>
</table>

The bar chart compares all the throughputs. The higher the bar, the greater is the throughput. We can immediately see that the smallest bar is the limiting process—the CNC tool. It can only produce 10 units in an hour. The assembly rate for the cabinets is lower, at 5 units per hour, but we have 5 joiners to do the work, bringing the throughput to 25 units, as illustrated by the dotted rectangle. The other two rectangles on the chart represent steps where a range of outputs is produced. It is rare for either of these process steps to achieve their maximum rates. The team will need to establish the reasons.

Team analysis found that the calibration sander was not always being used properly. The operators often took too much material off in one cut,
Figure 5.6  Capacity bar chart.
which could tilt the sanding belt. To compensate for the slope, the operator would feed the panels through correctly and then rotate the panels through 180 degrees to resand the high side. This accounts for the step in the range; that is, it was either a throughput of 10 or a throughput of 20.

The veneer issue is interesting. Where variation in throughput is seen, there is usually a problem to fix. The operator was provided with a sheet to record her hourly production rate over a day. She started at 20, and then her rate dropped over a couple of hours to 5. On a couple of occasions, she achieved 0. The cause: She could not find the veneers. The solution: The warehouse person set out the following day’s work in advance. Improving the layout of the complete veneer process increased the throughput here. There also were experiments with the adhesives to reduce the pressing time.

The CNC throughput was more difficult to resolve. Improvements included offline programming so that the operator could spend time running the tool and less setting it up, training a backup operator to enable covering of breaks, introducing a late shift for the CNC machine, some jobs being carried out manually, and long-term plans to buy another machine.

Therefore, using the capacity map, we want to know what it is that stops us from reaching the maximum possible production rate and to find a way to reduce any resistance to flow. There are a few established improvement methods: doing a job in parallel so that it does not affect production, using two operators in place of one, making sure that the operator does not have to wait for materials, having components delivered to the tool rather than having the operator get them, making sure that the operator is trained, and making sure that the machine operates properly.

When a company becomes experienced enough, it can add OEE data to the capacity chart. OEE refers to equipment. It is basically the percentage of production achieved as a fraction of the capacity of the machine when everything works perfectly. If the capacity of a machine is 100 units in a month but we get only 50 units of sellable quality, the OEE is 50 percent. The reasons for the reduction in performance are the same as we look for in this book—quality, performance, and availability.

When we create a process map, we ask the operators what their maximum throughput is. It is likely to be lower than the rate the machine is capable of. Precise data could be found from the equipment manuals or the manufacturer of the equipment, but we don’t want to scare the operators. The process of improvement is not about cutting jobs, although this is always
a fear of the operators. Consequently, operators will have a tendency to underestimate. Initially, I would accept the number they claim. Then, as they begin to learn the process, eliminate the issues, and develop trust in the application of Lean, we can start to increase the capacity.

Please refer to Chapter 6 for a variation on the value-stream map that considers capacity in terms of partial value.