Principles of Operations Chain Management

Understanding Bottlenecks

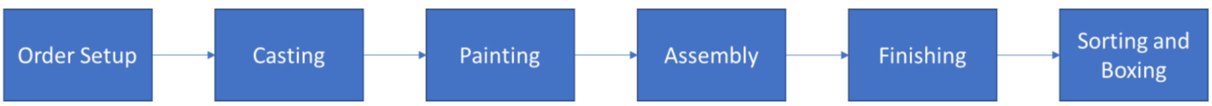
The **Theory of Constraints**, introduced and popularised by the book *The Goal. A Process of Ongoing Improvement* by Eliyahu Goldratt and Jeff Cox, is a body of knowledge that deals with all the obstacles that limit or constraint the organisation's ability to achieve its goals.

Computer simulations allow managers to approximate real-world phenomena without going through the expense of setting up and running an actual system. For this assignment, you are going to use a MS Excel spreadsheet to simulate a series of sequential processes in an industrial setting.

We will work on the case of a company in the miniature manufacturing sector. More specifically, they produce die-cast scale models of airplanes, ships, armoured cars, and other military artifacts for collectors.

Die casting is a metal casting process in which molten metal is forced into a steel mould under high pressure. The steel moulds, known as dies, are fabricated to produce castings with intricate shapes in a manner that ensures both accuracy and repeatability. In the toy industry, the castings are then painted, welded (or glued), and finally polished to provide an accurate scale representation of the original object.


The process consists of the following stages: order preparation, where the different materials (lead, zinc alloy, plastic, rubber, etc.) are prepared and sorted for processing. These materials are then taken to the Casting workshop, where the different parts of the miniature are moulded. The finished pars are then taken to the Painting station, and from there to the Assembly workshop, where the different parts and components are put together, welded, and glued to build the scale models. The Finishing station takes care of the inspection, polishing, deburring, washing, and finally varnishing of the finished replicas. Finally, all the miniatures are taken to the Sorting and Boxing desk, where orders are sorted together, and put in boxes ready for distribution.



In one hour, the Setup team can get ready materials for up 250 units in average. As this is a very simple procedure, the standard deviation is minimal, 5 units per hour. The casting team can only process 100 units per hour in average, but due to the nature of the process and the high temperatures required, it

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has a higher variability, with a standard deviation of 25 units per hour. The capacity of the painting station is in average 150 units, with a minimum of 50 (for more detailed miniatures) and a maximum of 250 (for models demanding less detail). The assembly team also works relatively fast and are capable of processing up to 200 units per hour in average, with a standard deviation of 20 units per hour. The finishing station oversees the quality control of the company and, therefore, tend to be slightly slower than the preceding units. They can process, in average, 100 units, with a standard deviation of 10. Finally, the sorting and boxing team can process up to 300 units per hour in average, also with an almost negligible standard deviation of 10 miniatures per hour.

The processing times at the Painting Station follows a uniform distribution in the indicated interval. All other station's capacities follow normal distributions with the indicated mean and standard deviation.

The factory works two uninterrupted 8 hour shifts per day. Breaks and other needs of the operators are already considered in the productivity data.

Part A

You will use random numbers to run a simulation of the 6-station manufacturing process described above, in the same way that you ran the simulation of the game described by Goldratt. You are expected to simulate a working day (16 hours) and to compute and observe the average throughput at each station.

For each station other than Order Setup you will have the following columns: "WIP Inventory" (WIP is the acronym for Work in Process), "Productivity", and "Throughput". For Order Setup you will only have the "Throughput" column.

As discussed in the tutorials, a uniform distribution can be simulated using **`=RANDBETWEEN(Min,Max)`**. To simulate a normal distribution use the command **`=CEILING(NORM.INV(rand(),Mean,StDev),1)`**. The command **`NORM.INV`** generates a random observation of a normal random variable with the indicated mean and standard deviation. The command **`rand()`** calls Excel's random number generator and returns a randomly generated number in the interval [0,1]. It does not require any input. The **`Mean`**, and **`StDev`** are the station's average production and its standard deviation. Those values are described in the two paragraphs following the schematic representation of the factory's process in the previous section. Finally, as we will be getting a real number, and we are talking about production units, the command **`CEILING`** rounds the number up to the closest integer. This means that the only two values that you need to change are, precisely, The **`Mean`** and **`StDev`**, the rest of the formula remains unchanged.

For each station, the "WIP Inventory" is equal to the "WIP Inventory" of the previous period, minus the station's "Throughput" in the previous period, plus the "Throughput" of the previous station in the current period.

The "Throughput" is the minimum between the "Productivity" and the "WIP Inventory". The "Productivity" is a random variable that represents the capacity of the station during the current period. If it is larger than the available "WIP Inventory" the production will be limited by the available inventory. Otherwise, if the "Productivity" is smaller than the "WIP Inventory", then the throughput of the station will be determined by its productivity.

Your table will have 16 rows. At the bottom, compute the total use of materials (sum of the Throughput of the “Setup” station) and the total production (sum of the “Throghput” of the Sorting station). Compute the average inventory for each station.

QA. Is there a station that accumulates significantly more inventory that the others? Which is the easiest way to reduce this inventory, without incurring in any investment in equipment or personnel?

<u>Deliverables for Part A</u>

1. One sheets in your MS Excel file, containing the simulation of one working day.
2. In your written report, you should include the answer to QA.

Part B

Adjust the “Throughput” of the station that you identified in Part A as the one accumulating large amounts of inventory, replacing the randomly generated number with a value that you consider reasonable. We will refer to this as the “target variable”. Build a table for a working day as in **Part A**. Remember that the throughput of one station causes accumulation of WIP inventory at the subsequent station. For example, the throughput of the “Setup” station may cause accumulation of WIP inventory for the following station, “Casting”.

Using the What-If function in Excel, build another table simulating 30 working days (a month). Include the following columns in your month table: “Materials”, “Setup Inventory”; “Daily Production”. The “Materials” column takes the sum of the Setup station’s “Throughput”; the “Setup Inventory” takes the average of the “WIP Inventory” column corresponding to the “Casting” station; and the “Daily Production” takes the sum of the “Throughput” of the “Sorting” station.

All the materials that are prepared at the Setup station and are not used at the end of the day, go to waste. Compute the total materials waste of the month as the difference between the monthly usage of raw materials (sum of “Materials”) minus the total production (sum of “Daily Production”).

Try several different values of the “target variable” until you feel happy with the resulting production and waste.

QB. Which is the “target variable”? What do you consider is its optimal value”? Does the monthly production seem to converge to a constant value as you increase the value of the “target variable”? Discuss the trade-off between throughput and waste. Is it eliminating waste completely a feasible target? Will it be economically viable for the company?

<u>Deliverables for Part B</u>

1. One sheet in your MS Excel file, containing the simulation of one working day, and the replication for one month.
2. In your written report, you should include the answer to QB.

Part C

Rather than fixing the capacity of one station, it may be worth investing in increasing the production capacity of another, either by expanding its capabilities, or by introducing some parallel processing.

To do this in a formal way, we first must identify the system's bottleneck(s). This can be done by finding the process or processes that cause more accumulation of WIP Inventory. If your results are correct, these must be the Casting and the Finishing stations. Let us focus on the Casting workshop first.

After some market research, our Operations team has found two possible improvements:

a) Introduce parallel processing by buying a new casting machine of the same characteristics of the first one.
b) Increase the capacity of the current machine, with the disadvantage that this increases the process variability. The new capacity would be and average of 250 units per hour, with a standard deviation of 80 units.

QC1. Test these two alternatives independently based on the initial configuration (**Part A**). Compute Total Production and Waste using the What-If tool as we did in **Part B**. Is there an alternative that clearly outperforms the other? Can you identify a new bottleneck?

Let us now focus on the Finishing station. At the moment, the station has 10 operators, who can produce in average 10 units per hour each, with a standard deviation of 3.16. The company has the following possibilities:

a) Hire 6 more operators with similar characteristics to the current ones. This will give an average production of 160 units, with standard deviation 12.7.
b) To semi-automate some of the processes in the station, increasing the productivity of each worker to 18 units per hour each with a standard deviation of 5 per worker. This will give a normal distribution with mean 180 and standard deviation 15.8.

QC2. Test these two alternatives independently based on the initial configuration (**Part A**). Compute Total Production and Waste using the What-If tool as we did in **Part B**. Is there an alternative that clearly outperforms the other? Can you identify a new bottleneck?

Your results in the previous two questions must have revealed the Painting Station as a potential bottleneck. If we analyse the station, we will notice that its output shows large variations, indeed, the standard deviation is $\frac{250-50}{6} = 33.33$. Therefore, we would like to find an alternative system that reduces the variability in the station's output. Our operations team has found that using air-brushes instead of the traditional painting techniques used in the factory, will change the distribution of the painting process to a normal variable with mean 230 and variance 25 (standard deviation of 5).

QC3. Test this alternative based on the initial configuration (**Part A**). Compute Total Production and Waste using the What-If tool as we did in **Part B**. What could be the effect of changing the painting technique? Is it worth investing?

Once you have arrived at this point, you may have noticed that, irrespective of the other bottlenecks, the slow casting process generates large amounts of waste and, therefore, it must be addressed. But also, Painting and Sorting require some work. It does not seem efficient to address these bottlenecks independently, they must be tackled together.

QC4. Analyse different combinations of the alternative processes for Casting, Painting and Finishing that we have analysed in this section and identify the best alternative for the company. Would you suggest also reducing the input from the Setup team? By how much? Is a fixed amount the best alternative? Would you be able to figure out a better decision rule for the amount of materials that is processed by the setup station every hour?

QC5. What is the overall effect of the changes introduced? What was the impact in productivity? What in waste? Has a new bottleneck arisen? What can you conclude in general about bottlenecks and process re-engineering?

<u>Deliverables for Part C</u>

1. One sheet in your MS Excel file, containing the simulation of one working day, and the replication for one month, for each of the five cases described in **QC1** to **QC3.**
2. As many sheets in you MS Excel file for the different alternatives you tested in order to find the best set combination of processes for Casting, Finishing, and Painting altogether.
3. In your written report, you should include detailed answers to questions in **QC1** to **QC5**.

Comment

You are expected to prepare a 1200-1500 words report based in your simulation experiments. The answer to the questions in this document should not be provided in a question/answer manner but, instead, embedded in the document in a single narrative where you discuss your findings and the implications for the company. Whenever possible, use textbooks and other academic literature to support your claims, or to provide theoretical grounds to your assertions.

Further details can be found in the coursework specification form.