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Understanding The Beer Distribution Game

Using Systems Thinking to improve game results

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Understanding The Beer Distribution Game

Using Systems Thinking to improve game results

An investigation of the effect of different playing strategies

#BPTK #System Dynamics #Business Prototyping #Beer Distribution Game

1. Introduction to the Beer Distribution Game

The Beer Distribution Game was originally developed at MIT in the 1950s to illustrate how difficult it is to manage dynamic systems – in this case, the dynamic system is a supply chain that delivers beer from a brewery to the end consumer.

You can find the code for the simulation models along with a Jupyter notebook version of this blogpost on our GitHub repository.

What makes the game so intriguing is that the structure of the supply chain and the rules of the game are simple, yet the resulting behavior is quite complex. The Beer Distribution Game is well documented: you can find my favorite description of the game in Peter Senge's worldwide bestseller "The Fifth Discipline", John Sterman's Business Dynamics a nalyses the game using system dynamics stock and flow models.

You can play the Beer Distribution Game online at beergame.transentis.com.

2. The Challenge: Managing The Supply Chain

To understand the challenge of managing a supply chain, let us take a more detailed look at its structure – the supply chain leads from the brewery, via a distributor and wholesaler to the reseller, who sells beer to his customers, the end consumers.

The objective of the game is to ensure that the consumers' demand for beer can be met directly or at least with as small a delay as possible while keeping each player's inventory as small as possible.

The sketch below illustrates the supply chain and the flow of information along with it.

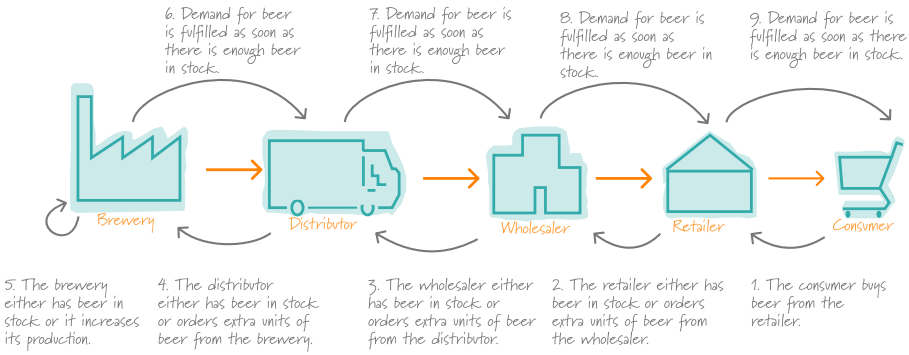

Figure 1: The Beer Supply Chain

Initially, customer demand for beer is stable at 100 units per week and the entire supply chain is in a steady state. Each member of the supply chain has an inventory of 400 units.

The rules of the game are simple – in every round each player performs the following four steps:

1. **Check deliveries.** Check how many units of beer are being delivered to him from his supplier in the supply chain
2. **Check incoming orders.** Check how many units of beer his client in the supply chain has ordered.
3. **Deliver beer.** Deliver as much beer as he can to satisfy the customers' demand (Note: in our implementation of the game above, this step is performed for you automatically).
4. **Place outgoing order.** The difficult step is to decide how many units of beer the player needs from his supplier to keep his inventory stocked up and to ensure he has enough beer to meet future demands.

"Note: In the single player version of the game that I included above, you play the role of the retailer. The other roles are played by the computer, i.e. the order decision for these players is made by the computer according to a predefined order policy (the order policy the computer follows is essentially the one developed in this blog post)."

3. Some Pitfalls to be Aware of

There are three pitfalls in the Beer Distribution Game that players need to be aware of:

- **Delays.** Because of the nature of supply chains, the players' demands for beer may not be fulfilled immediately – their supplier may also not have enough inventory and will then have to pass is own order up the supply chain. There is a delay of at least one week in each direction, i.e. a changed order will not be delivered for at least two weeks, even if there is enough stock in the suppliers' inventory.
- **Inventory Costs.** If you order too many units of beer, your inventory costs will rise, because you will need more people to handle the beer and more storage space. Each unit of beer has an associated inventory cost of EUR 0.5 per week. Because you cannot downsize your storage space to zero, the minimum inventory cost is always EUR 200, even if your inventory goes down to zero. Hence the target level of beer units in your inventory is 400 units, you should try to reach 250 units by the end of the game.
- **Backorder Costs.** If you order too few units of beer, you may not be able to meet your customer demand for beer. Backorders are also penalized, each unit of beer on backorder cost EUR 1 per week. Hence the target is to keep the backorder at 0.

4. How Game Performance is Appraised

At the end of the game, each player gets a personal performance appraisal. Given the rules of the game and the pitfalls mentioned above, there are two relevant performance measures:

- **Individual Supply Chain Cost.** This is the accumulated cost of the player's part of the supply chain, i.e. the sum of his inventory and backorder cost over time. The individual supply chain cost target is to keep the accumulated cost below EUR 8,300 throughout the game.
- **Total Supply Chain Cost.** This is the total supply chain cost. It is important to keep an eye on this because the individual player could improve his own cost at the expense of the other players in the supply chain – we will see how this happens shortly. The total supply chain cost target is to keep the accumulated cost below EUR 29,300 throughout the game.

5. Supply Chain Dynamics

5.1. Dealing With Changing Demands For Beer

As I mentioned earlier, the entire supply chain is in a steady-state initially and the consumers' demand for beer is stable at 100 units per week. Of course in the "real world" demand is never constant, which is one of the reasons why managing a supply chain is not easy in the first place.

What makes the Beer Distribution Game so interesting (and perhaps also frustrating) is that the consumers' demand for beer does not fluctuate wildly, on the contrary, it actually only changes once: the consumers demand beer quadruples from 100 to 400 units in the second week and then remains at 400 for the rest of the game.



Figure 2: Understanding the Beer Distribution Game Blog Post Graph 2 EN

Nevertheless, typical game results look something like those displayed in the graph below: even though the consumers' orders never rise above 400, the retailers' orders are close to 1000 for a long time. This leads to a huge "whiplash" effect along the supply chain, resulting in peak orders of well over 30,000 units in the brewery.

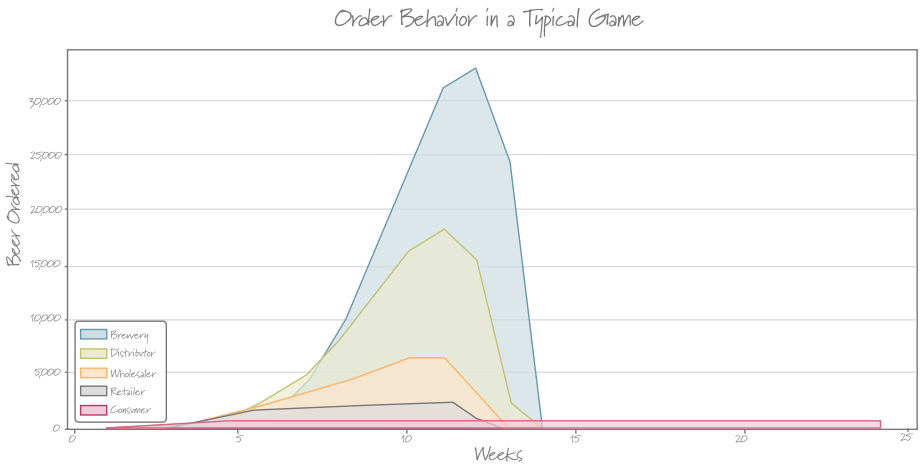

Figure 3: Understanding the Beer Distribution Game Blog Post Graph 3 EN

Given this order behavior, it is not surprising that players build up huge inventories which take more than 2 years to deplete, given that the consumer orders are constant at 400 units per week.

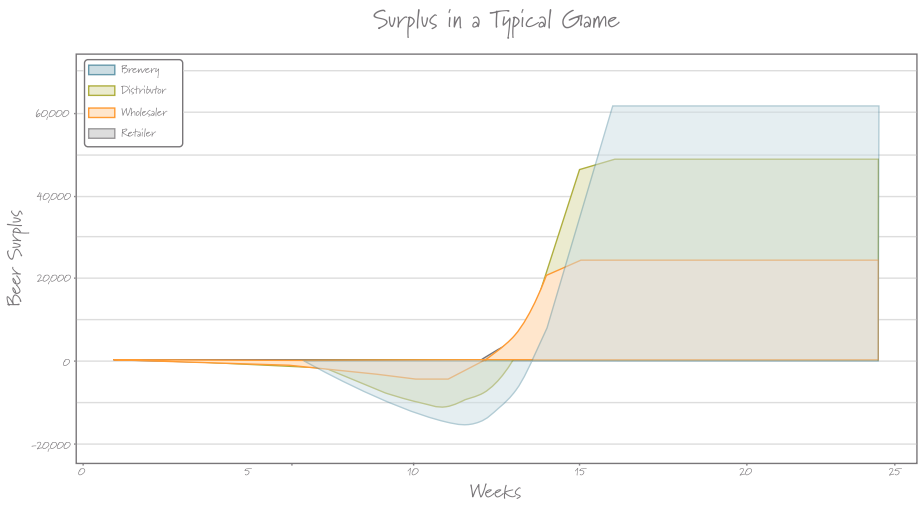

Figure 4: Understanding the Beer Distribution Game Blog Post Graph 4 EN

To understand why most players' order behavior is like this initially, we need to understand the feedback loop that governs each player's order decision.

5.2. The Feedback Loop Governing The Players Order Decision

Each player's objective is to satisfy incoming orders and to balance his inventory at a level close to the target inventory. So given the information available during the game, each player's behavior should be balanced by the feedback loop displayed below:

- At the end of each round of the game, the player establishes his current inventory by adding the incoming beer and subtracting the outgoing units of beer from the inventory.
- He then checks the customer's current demand for beer, his target inventory and his current inventory and decides how many orders to place.
- The player's supplier will (presumably) do something similar and will eventually deliver the beer that the player ordered.

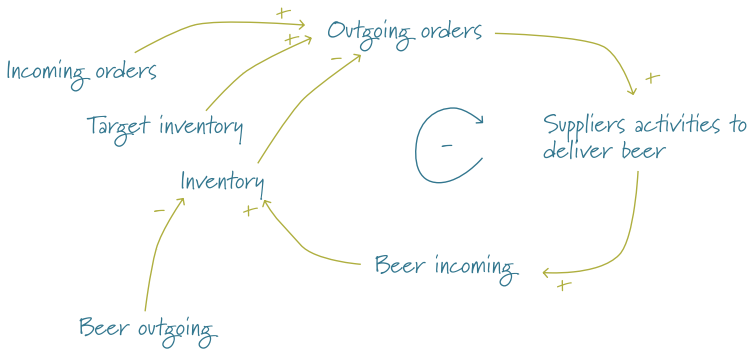

Figure 5: Understanding the Beer Distribution Game Blog Post Graph 5 EN

The feedback loop is actually very simple, so what goes wrong?

Initially, the problem is a psychological one: Yes, the feedback loop is simple, but an important part of that loop is invisible to the player and thus out of his control. I have illustrated this below.

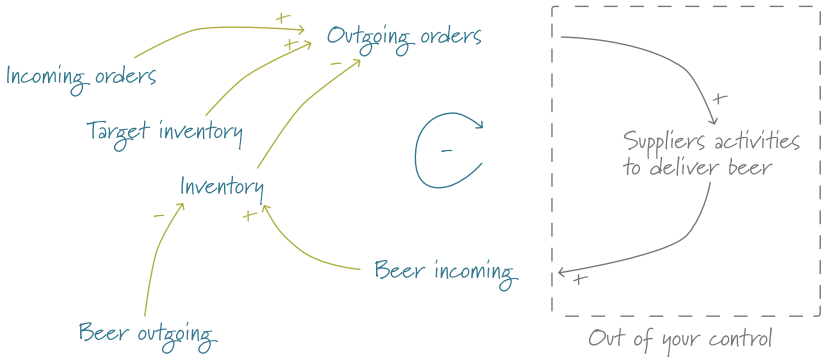

Figure 6: Understanding the Beer Distribution Game Blog Post Graph 6 EN

So what really happens is this:

- The player places his order and waits for the beer to arrive.
- And waits.
- No beer is delivered.
- The number of units on backorder begins to increase. So do the costs and hence the player's anxiety level.
- Perhaps the order never arrived? Better to order more next time...

So even though the units that are on backorder have already been ordered, many players add the units that are on backorder to every new order just to be on the safe side, thus creating the positive feedback loop displayed below. Orders increase exponentially until eventually a huge amount of beer is delivered.

```
Outgoing Orders = Incoming Orders + Target Inventory - Inventory + Backorder
```

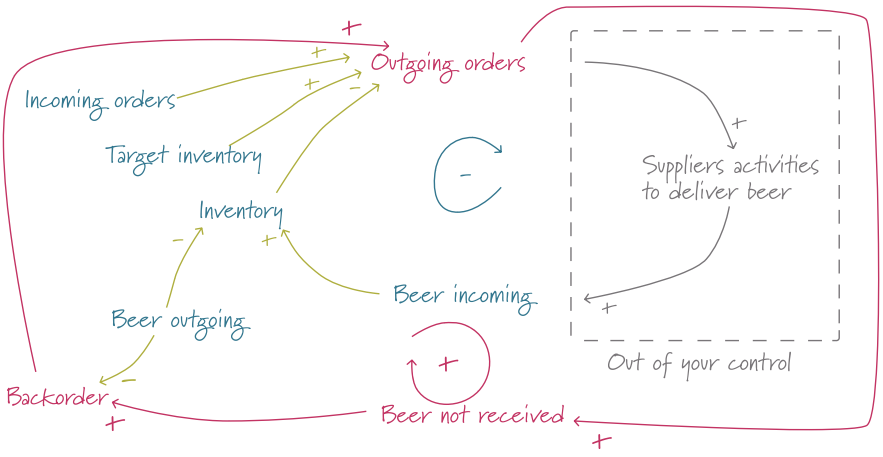

Figure 7: Understanding the Beer Distribution Game Blog Post Graph 7 EN

Thus the first step to improving game results is to ignore backorders when making ordering decisions.

6. Improving Game Results

6.1. Ignoring Backorders

Given the balancing feedback loop above, what should the ordering policy look like?

The simplest approach is to check both your incoming orders and the level of your inventory every week and then to order enough to account for your desired inventory:

```
Outgoing Orders = Incoming Orders + Target Inventory - Inventory
```

You can test this strategy for yourself in the game above!

Though this leads to drastic improvement, the results are still not really satisfying, as you can see in the graph below that shows the order behavior and the resulting inventory.



Figure 8: Understanding the Beer Distribution Game Blog Post Graph 8 EN

The inventory still rises to a considerable amount – the reason is that the policy defined above still leads to over-ordering because the policy “forgets” about the orders that have already been placed.

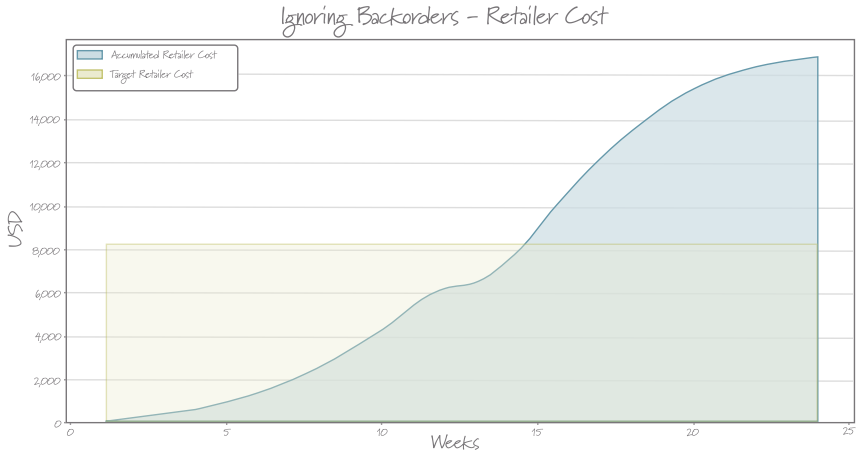

Figure 9: Understanding the Beer Distribution Game Blog Post Graph 9 EN

So let us see what happens when the ordering policy takes open orders into account.

6.2. Remembering Open Orders: Including The Supply Line

Our next step to improving our ordering policy is to remember how many items have already been ordered and to take this into account in our order decision – to avoid confusion, I will refer to this quantity as the supply line.

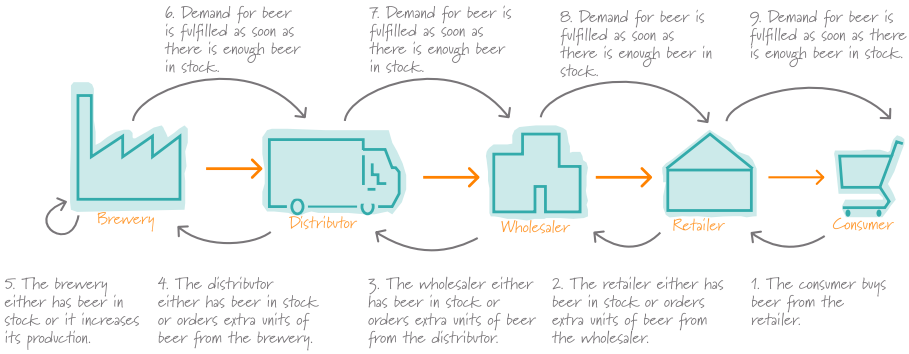

Figure 10: The Beer Supply Chain

If we include the supply line in our feedback loop, we arrive at the following diagram:

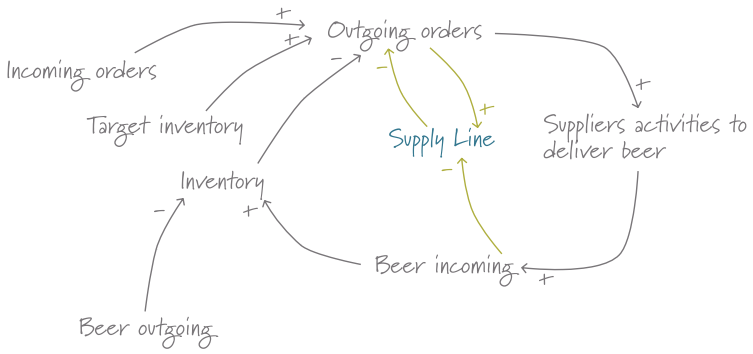

Figure 11: Understanding the Beer Distribution Game Blog Post Graph 10 EN

We now keep track of the outgoing orders in the supply line – every time an order goes out, the supply line also increases; as soon as new units of beer arrive, the supply line decreases. When we decide how many items to order, we also include the supply line in our order decision. This ensures that we never order an item more than once.

How many items should be in the supply line at any time?

To estimate this, let us perform a little thought experiment and assume our inventory is zero and our customers order exactly 100 units every week and that we do not worry about back orders. Then for the system to be in a stable state, we need to have 100 units delivered every week (which we then pass on directly to our customer, the consumer).

Because it takes two weeks for items that are ordered to be delivered, the customers who order in the first week do not get any beer at all (sorry!), but we order 100 units. The customers in the second week also do not get any beer either (sorry!), but again we order 100 units. Now there are 200 units in our supply line.

In the third week, our initial order finally arrives. We pass this delivery on to the consumers and place another order of 100 units. From now on we can always satisfy the consumers' demand. Our inventory is always zero, and we permanently have 200 units in our supply line.

What would change if the consumers did not always order 100 units but 200 units instead? Well in that case our supply line would be at 400 units (2 weeks time 200 units).

From this we can deduce that our open orders should always be equal to:

```
Target Supply Line = Delivery Delay * Incoming Orders
```

Note: Of course this is formula is only true if the delivery delay is stable and so are the items that are ordered – to improve our estimate for the target supply line we ought to replace the delivery delay by the average delivery delay and the items ordered by our expectation of how many items will be ordered. However, to keep our analysis simple I will not include this for now, but we should remember that for further exploration.

I have included an updated version of the causal loop diagram below.

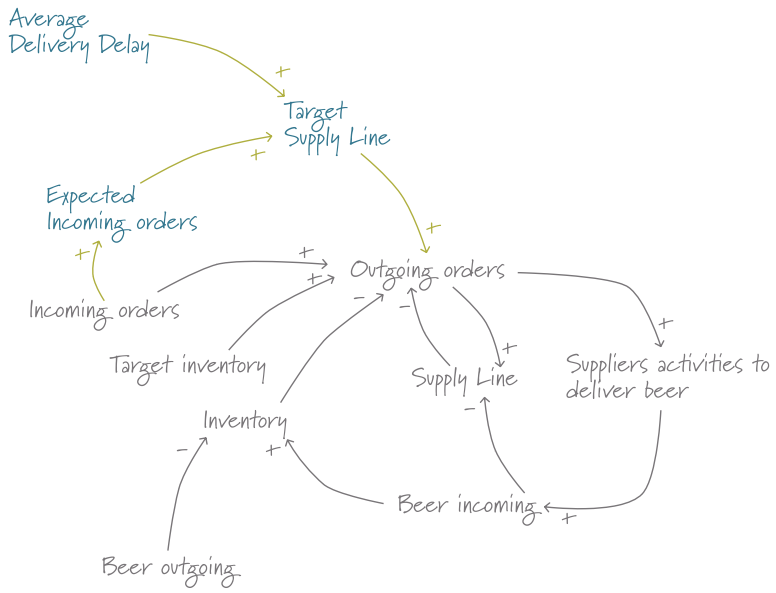

Figure 12: Understanding the Beer Distribution Game Blog Post Graph 11 EN

Given our new causal loop diagram, we can also formulate a new ordering policy:

```
Orders = Incoming Orders + Target Inventory - Inventory + Target Supply Line - Supply Line
```

Again you can test this strategy for yourself in the game above. It takes a little effort to track the supply line …

The results now look much better – the order peaks are smaller and less sustained. The target inventory is reached after 17 weeks.

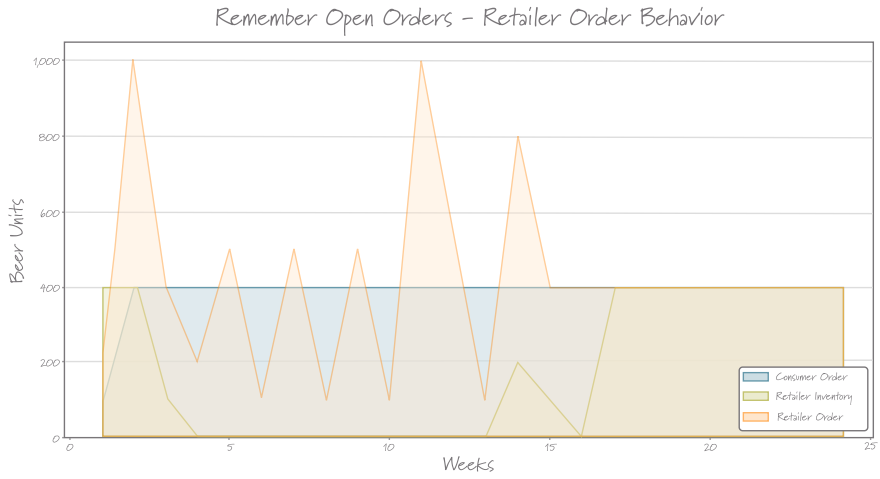

Figure 13: Understanding the Beer Distribution Game Blog Post Graph 12 EN

The cost structure now also looks much better, we just manage to stay within the cost target:

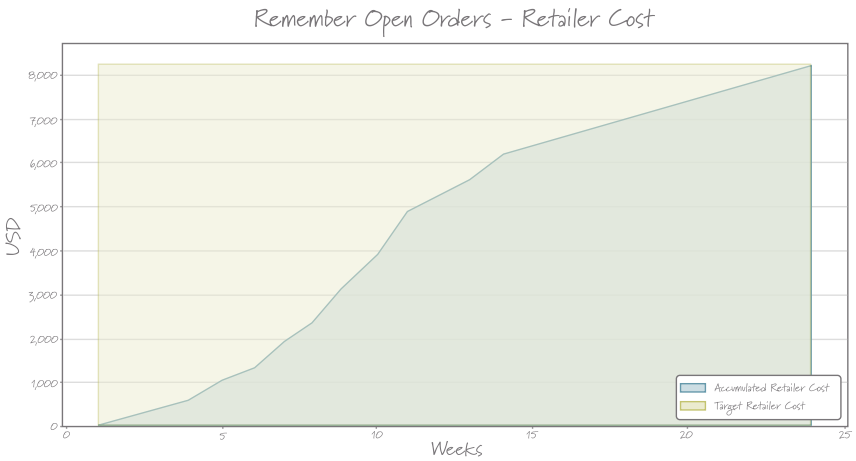

Figure 14: Understanding the Beer Distribution Game Blog Post Graph 13 EN

Our surplus is also looking good, we easily reach the surplus target:

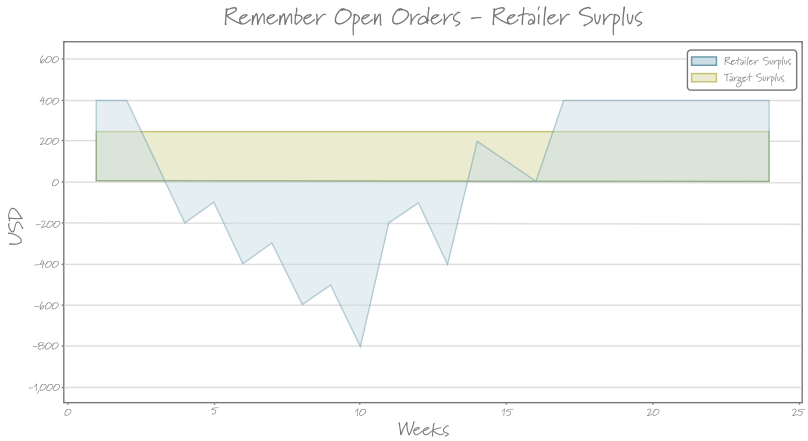

Figure 15: Understanding the Beer Distribution Game Blog Post Graph 14 EN

6.3. Avoiding The Bullwhip Effect

Unfortunately, our new ordering policy still leads to a huge bullwhip effect – this is because each of the players in the supply chain uses the same ordering policy and tries to ensure that the target inventory level is reached and the order pipeline is filled. Because the consumer places a larger order, the retailer has to place an even larger order. And the wholesaler then places an even larger order ... you can see this effect nicely in the graph below.

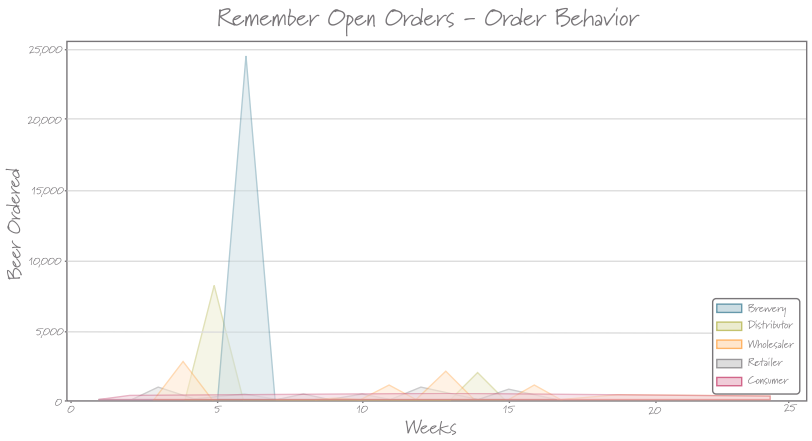

Figure 16: Understanding the Beer Distribution Game Graph 15 EN

Because of these order peaks, the total supply chain cost also explodes and is still way beyond the cost target.

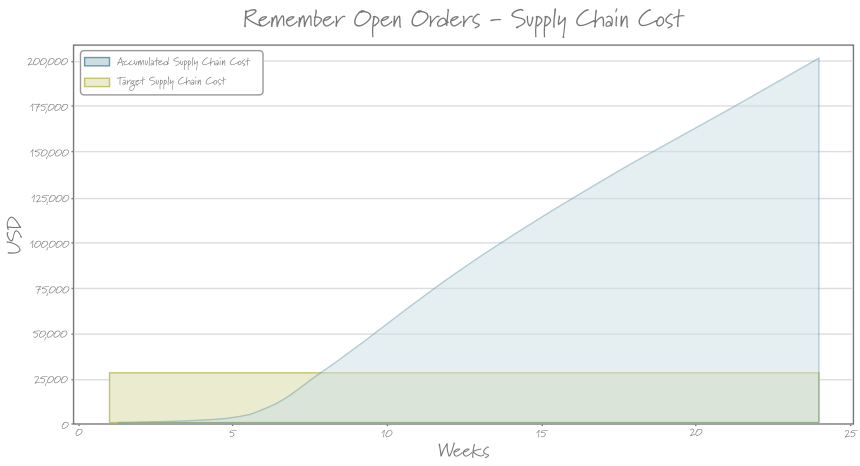

Figure 17: Understanding the Beer Distribution Game Graph 16 EN

How can the bullwhip effect be avoided?

The key to avoiding the bullwhop effect is to avoid placing orders that are significantly different from last weeks orders – so instead of trying to adjust the actual inventory to the desired inventory as quickly as possible, we do this gently over a longer period of time, as in the following order policy:

```
Orders = Incoming Orders + (Target Inventory - Inventory + Target Supply Line -
Supply Line)/Inventory Adjustment Time
```

I have updated the causal loop diagram to include the inventory adjustment time which defines how much time we allow to adjust the inventory to the desired level:

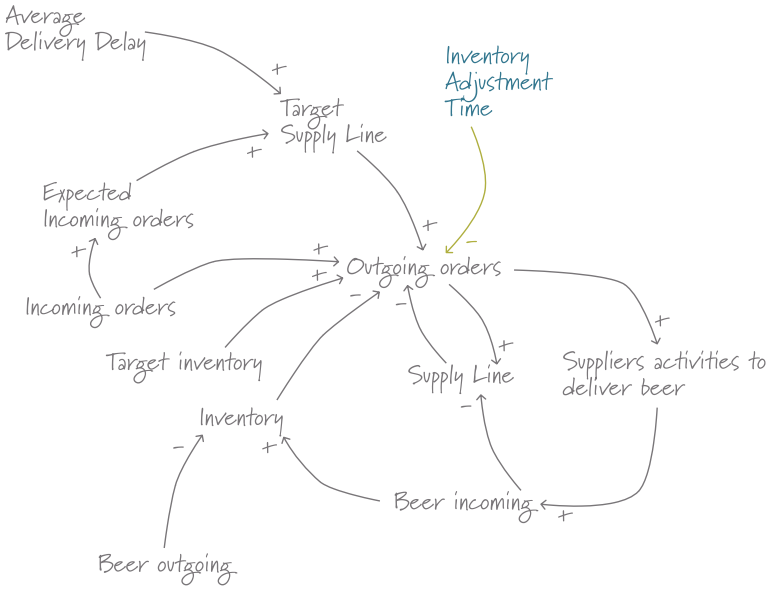

Figure 18: Understanding the Beer Distribution Game Graph 17 EN

The graph below shows what happens when we set the inventory adjustment time to 8 weeks.

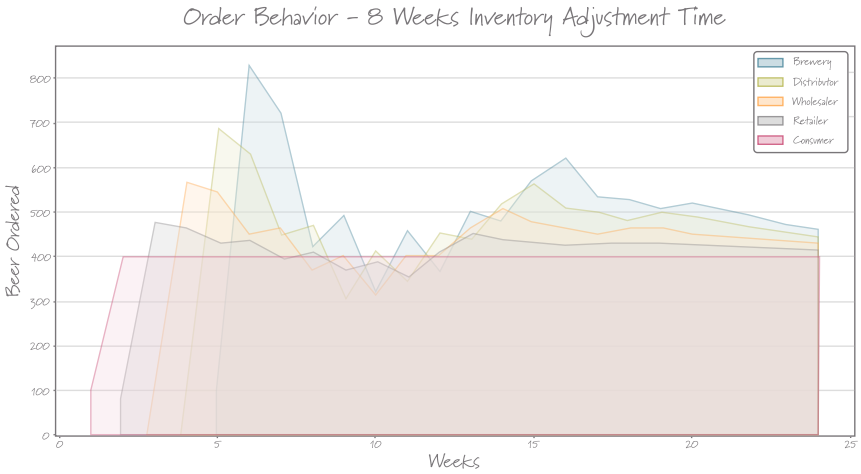

Figure 19: Understanding the Beer Distribution Game Graph 18 EN

With these settings, we reach all our performance targets.

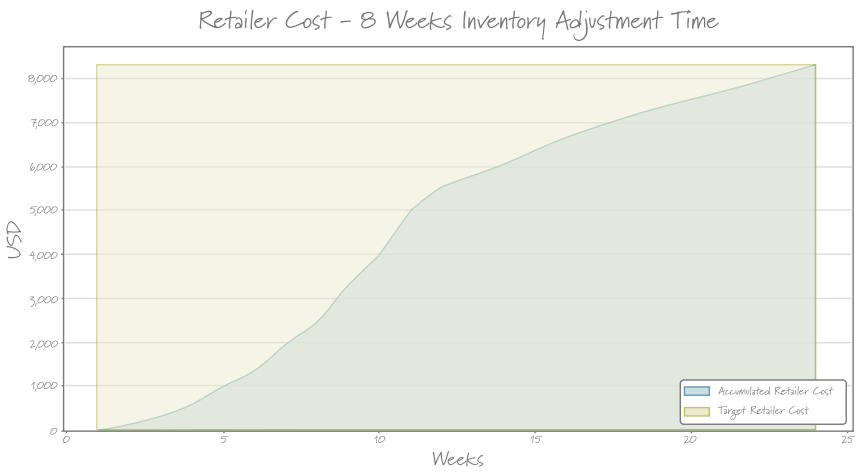

Figure 20: Understading the Beer Distribution Game Graph 19 EN

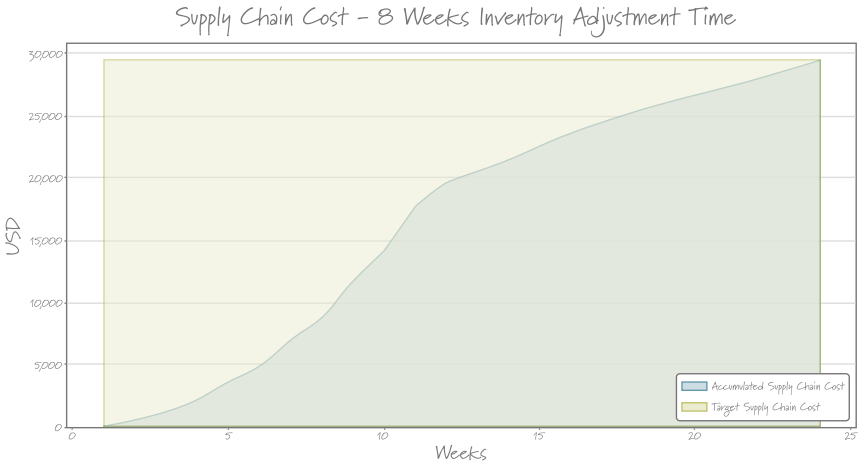

Figure 21: Understanding the Beer Distribution Game Graph 20 EN

The surplus also reaches the desired level – given even more time, the inventory would adjust to the desired level of 400.

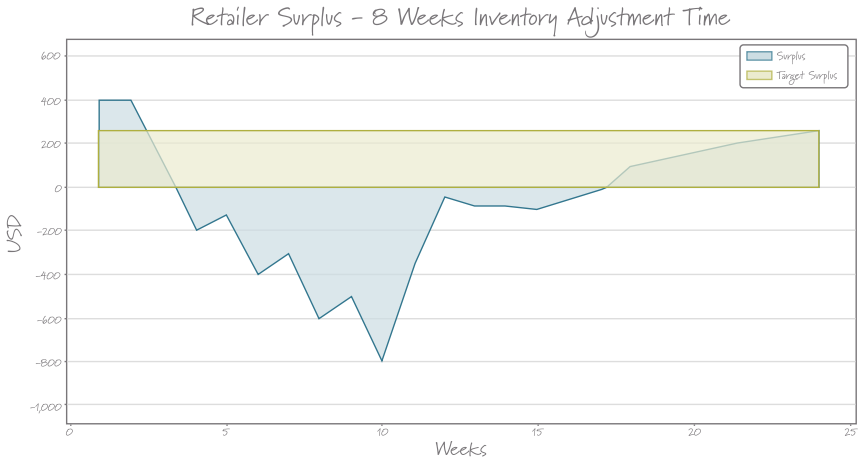

Figure 22: Understanding the Beer Distribution Game Graph 21 EN

Of course, there is a trade-off here – because we adjust the inventory slowly, we are out of stock more often and hence our service level towards our customers in the supply chain goes down. But in the Beer Distribution Game, this is outweighed by the performance target we have for keeping the total supply chain cost low.

To illustrate this trade-off we can take a look at how the retailer surplus and the total supply chain costs vary with the inventory adjustment time.

The graph below plots the retailer surplus for different inventory adjustment times. The shorter the inventory adjustment time is, the quicker the surplus gets back above zero and the quicker we reach the desired inventory of 400.

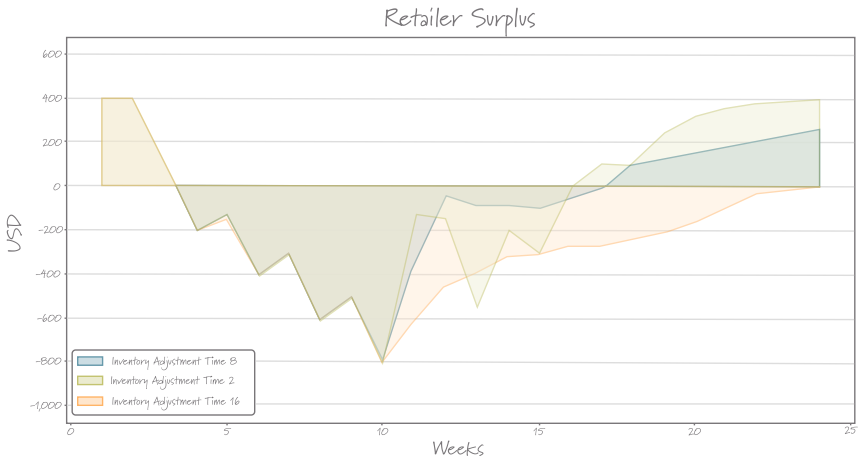

Figure 23: Understanding the Beer Distribution Game Graph 22 EN

On the other hand, the graph below shows how the total supply chain costs vary with the stock adjustment time – the interesting effect here is that a stock adjustment time of 16 weeks has a lower overall cost attached to it initially but in the long run the stock adjustment time of 8 weeks performs better. This is because the total cost includes penalties both for being out of stock and for being overstocked – if the adjustment time is to short, then some of the suppliers are overstocked and hence the cost increase. If the adjustment time is too long, then eventually all suppliers will be out of stock, which increases the total supply chain cost.

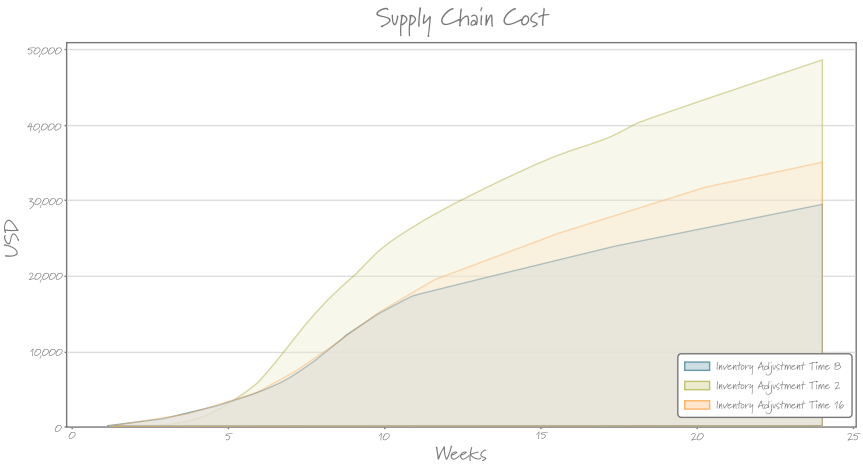

Figure 24: Understanding the Beer Distribution Game Graph 23 EN

The ordering policy above is the policy that we have implemented for the single player version of the game presented above.

7. Where to go From Here: Redesigning The Entire Supply Chain

This post explains the dynamics behind the Beer Distribution Game. It illustrates how to analyze and improve the ordering policies of individual players in the supply chain using causal loop diagrams and some live experiments with the game.

Of course in reality it would be risky and expensive to perform such live experiments with your supply chain– that is why it is useful to build simulations that give you the opportunity to perform risk-free experiments.

I have included such a simulation model below, to give you the opportunity to experiment with the changes to the ordering policy we have been discussing:

Embedded content: https://app.metapad.ai/embed/16cf74a7-e642-4277-b22a-8b5576bca422/eaadcfee-480b-4d66-a961-42965de61205

Our analysis of the supply chain also points to further improvement potential – the way the supply chain in the Beer Distribution Game is structured, each player only communicates orders to his immediate supplier in the chain, therefore it takes quite a long time to react to changes in customer demand.

Surely we could improve the performance of the supply chain if the consumers' demand for beer were communicated to all players in the chain directly?

So instead of just taking a local view of each player's behavior, we could take a global view of the entire supply chain; instead of just improving each player ordering policy we should change the architecture of the entire supply chain.

Needless to say that this is what actually happened in the "real world", we just need to look at just-in-time production and lean manufacturing (and let us not forget that the Beer Distribution Game was developed in the 1950s before these revolutions took place).

Though these ideas are very exciting, I feel we have achieved enough for now and will therefore leave a detailed investigation of these ideas to a future post.

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