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HAZHIR This week, we are looking at the market growth model. So this is kind of inspired by Forrester's market growth,
RAHMANDAD: but has a few additional components to it. So I kind of have that there is a total market size and this is a durable product, so there is a replacement purchase and there is a first time purchase type of a dynamic. The part that is the product is sold through the direct sales force is pretty similar to Forrester.

And you start with a fraction of total revenue being allocated to the sales force, and then their productivity depends on the delivery delay, but also on availability of customers. And that's kind of the additional component to the classical market growth model of Forrester.

There is a manufacturing operation. You have a backlog for ordered products. You are not holding inventory, so it doesn't have the complexities of inventory management. It has a little bit of additional piece for backlog management. And then it's kind of calculation of excess delivery delay.

So those are the big picture of what the scope of the problem was. Hopefully, you have worked on it and you know the challenges. It would be good to hear your thoughts on the challenges you have faced in terms of things that you noticed where-- and let me just make this screen. Oh, actually, you can just type here. Let's see.

AUDIENCE: Not a specific formulation, but I just found this one very difficult to do iteratively.

HAZHIR Interesting.

RAHMANDAD:

AUDIENCE: Like it felt like everything tied very closely into each other. So as I was trying to come up with the formulation for one thing, I found that I needed to do a lot of structures for the other. And then when I had problems, I found it more difficult to diagnose as a result.

HAZHIR Interesting. So can you tell us what was your process? Where did you start, and where did you find it more

RAHMANDAD: challenging to isolate?

AUDIENCE: Yeah, so I started, I think, with the order backlog through to delivered goods, just trying to make the very basic framework there. But then I felt like I needed to go a step up from that of how many orders there were. I felt like I needed some level of the sales force immediately. And because I needed the sales force immediately, I felt like I needed revenue immediately, because I felt like I needed revenue immediately. It all just played in together at once.

HAZHIR I see, I see. So this is actually a very good question and approach. That is, you want as much as possible to have

RAHMANDAD: chunks of model that are fairly clean, independent, and then you add a chunk. And so I like Jake's approach, trying to do that.

And this model, in my view, is not necessarily that much harder to do it compared to many other models. Perhaps even some of the chunks are easier. And your approach was good. So you have a kind of a production sector, the production. There is a production capacity, orders are coming in and are going into the backlog, and then delivered out of the backlog.

So that part you can formulate and have exogenous orders. That's actually how you would do it. You can create exogenous orders, have a step function, go into it, see how things go, have exponential growth going into it, how it works, and be done with that part.

Then there is a mechanism for ordering, and there the exogenous drivers might be available customers and delivery delay that is perceived. So if you make those two as exogenous inputs into the sales force productivity effectiveness part, that can also create its own chunk of a structure.

And then what remains? So the delivery delay is coming from the production side. And then yeah, that would be it. Now, there is a market side if you want to have it separately. That is how many customers are available. So I think with those three chunks, you could isolate each of them relatively smoothly. So the customer side, there will be a sales force coming into it or even a sales rate coming into it, and that will take care of it. That would be how I would cut it. But we can go through some of the examples or how different students have done it and see how that has been tackled.

Good. Other challenges?

So we can-- let me just close this thing so it doesn't confuse us. Let's look at the submissions.

OK, so let's actually do a little bit of a browsing of models for sector. So this is Ross's we have. And let me just-- so we have the demand side, potential demand. Hmm, that's interesting. So, yeah. That's interesting.

Yeah, so I like it. This is actually an interesting way of doing it. I have to look at the formulations. But basically, Ross is kind of formulating the customer sector and the demand part together in a single stock and flow structure, which should work fine. Then we have the reputation, we have the sales force, and we have the factory building part. So these are the right stocks in a high level view. That's great. Let's look at a few more.

Album has production capacity and production capacity work in process, backlog, tracking of profits, potential customers, customers, and then the return rates. That depends on the differentiation. And then you can get the sales from that return rate and sales force. So pretty much the same key stock variables. Great.

Oriana. We have sales force. We have reputation for delivery delay. We have customers who are moving between interested and current. And there is we should see what that part is done and then potentially interested. So there is a little bit of additional diffusion dynamics, maybe, here. We should look at that.

So actually, can you tell what is the distinction between the three categories? So customers are the ones that currently have the product. Interested customers are the ones who want to buy it. So that creates--

AUDIENCE: So my idea was that there's whatever product there is, they're going to be like x could potentially have use for it. And then the sales force lets those people know that it exists. Then out of those people who now know that it exists, depending on the reputation of the company, a certain portion are going to buy.

HAZHIR I see.

RAHMANDAD:

AUDIENCE: I never-- like, there should be a return back, like customers and interested customers back potentially, like--

HAZHIR I see. So in a sense here, the sales force is not needed for repeat purchases, for replacement purchases? Is that a

RAHMANDAD: correct understanding?

AUDIENCE: Yeah, but if I just added an additional flow pack, it would--

HAZHIR Yeah, so either you could take them here so that now they have to be, or the rate for purchase here could be

RAHMANDAD: bottlenecked by the availability of sales force rather than just being kind of a fraction based on reputation. So that would be another way to do it. But then you didn't even need the potentially interested customers. You could have one. Got it.

And then you have the view for the backlog. So you have the backlog, factory, authorized number of factories. So this is capturing the delay in the process of generating factories. And the units are OK. That's great.

AUDIENCE: May I just ask a question?

HAZHIR Sure.

RAHMANDAD:

AUDIENCE: How did you deal with the depreciation rate of both vectors?

HAZHIR So this is a first order depreciation in this case.

RAHMANDAD:

AUDIENCE: I meant in deciding how many to construct.

HAZHIR Oh, construction of factories. So this is coming from pressure to expand factories, which is coming from delivery

RAHMANDAD: delay. And then there is-- so we haven't yet gone through these equations. So I just wanted to get a quick overview of the structures or the stocks that different students are using. Then we can go through the equations. I think there might be issues that could be improved here.

Let's see if this is-- searching. So we have the customers who are interested and those who have purchased. So this is pretty similar to the first couple of-- and then sales force impacts that purchase rate. It's kind of a little bit complicated there. We need to look at the equations.

Orders come here. That creates a delivery delay through shipment, which depends on the stocks. Perceived capital stock. And then perceived delivery delay is impacting the expansion of capacity. So that also makes sense. There is the issue of capacity, capital stock adjustment time, and how that is captured or kind of work in process for capital is not explicit here, but otherwise looks good.

Ann's model, let's Zoom in a little bit. So we have customers who are potential, then become interested. Then they're waiting for their orders. So Ann is accounting for this intermediate stage of waiting orders. We'll have to look at this equation to see how it maps into the backlog story.

This adds a little bit more complexity, but core concepts are similar. Sales force is straightforward. And then cash reserve for sales force wages. So she's accounting for money in the bank, rather than directly taking the sales force from revenue. So that adds one more stock that others didn't have. It's OK, but may not be necessary. And then we have the facilities and death of the buildings, or death to buildings. That's very revolutionary. OK.

And then we have here Hisam's products that are owned, orders that are in backlog, potential customers. So this is kind of capturing backlog similar to Ross in the same stock and flow structure as the customers. And that should work fine. We have the sales force driving the sales. It should also have some impact on-- yeah, so that kind of takes people back here. So there is kind of a question there, whether that's the best way to handle it or not.

Then production capacity under development and production capacity. Great. And then did we check? Yes.

Gerard's model has the reputation for delivery delay, I assume, adopters, and those who become willing to rebuy. So that's kind of the purchasing part. There is more complexity here in terms of potential adopters becoming interested. And then you can convince those interested into becoming adopters.

That's fine. It's an interesting alternative because you're now using sales force to drive interest, and then these people, maybe with a delay, adopt. And that delay is regulating how likely it is for them to adopt. And alternatively, they may decide not to adopt.

So this is a little bit of a different conceptualization, which might be pretty good. I have to look at it a little bit more closely. And then we have the similar production capacity dynamics here. This one is Alexander. So we-- yes. Backlog, installed base.

So you have a little bit of a co-flow of products versus customers. And that's also nice to have. You account for different units, for people versus products. Sales force, and then you have in the other view the capital, the production capital as a single stock.

And then we have Jason's, so potential customers versus customers with the sales rate. Order fulfillment has the delivery delay and backlog. And then delivery delay gets perceived by customers separately than by the company. All of that makes sense? Capacity acquisition.

So we have the capacity and capacity under development. So that's also fairly clean and standard. And then sales force is just the stock sales force, which makes sense, with some adjustment time. OK, good.

This is Cathy's. Let me see if I missed somebody. No. Cathy's. So accounting is the last group. So we have customers who are potential with purchase orders with the product. So customers with purchase orders are the ones waiting in the backlog of stock, basically. So they have the-- yeah. And then customers with the product, and then customers who don't have the product, and then they need to decide to come back. So this takes care of backlog and-- yeah, so all of that is accounted for. It's actually an interesting piece.

So a quick look at this structure. What it tells me is that-- so this is a quick deeper dive into to a heuristic you can use. So I look at this stock and flow structure. If you put all of the stocks together as a bigger stock, what are the inflows? Do you see any inflow to that full stock and flow structure? Nothing.

What about an outflow? There is an outflow. So as soon as I see that, it tells me that ultimately, this market will be drained to nothing. And that is kind of a little bit of an unrealistic setup. So kind of zooming out and thinking of a mix of stocks and flows, whether they are together, conserving whatever you are trying to do or not, and they potentially lead to an absorbing state that is nobody or nothing, that's kind of important to have in the back of your mind.

Now, sometimes that is realistic. That is, for some things there is actually an absorbing state where there is nobody left or no money left, or whatnot. But in this case, I think that's not, probably, the most realistic alternative.

And then you have rookie sales force, experienced sales force. So there is kind of additional dimension of rookie dynamics, which are pretty relevant, even though it wasn't part of the problem definition. That's nice to have.

And then you have the backlog and the manufacturing capacity. Now, this is also a little bit more complex here. You have units in production queue. So this is kind of the back, the normal backlog, the way I would have thought about it. But then you have units in production. So we should look at these in a little bit more depth. I don't know.

AUDIENCE: I was thinking that the units in production queue, that's just-- like, that's the list of customers or orders I need to fill. And then I'm limited by my capacity on actually starting the manufacturing process. So I separated those.

HAZHIR So your manufacturing process kind of limits the production starts. And after a fixed time, they end, basically.

RAHMANDAD: Yeah, and your total backlog would be the sum of these two. So you would have the delivery delay calculated correctly, that average delivery delay.

Yeah, that's fine. It's sounds right. It's probably overkill, in the sense that you don't need two stocks to capture this process. Basically, if you had the outflow to be regulated by manufacturing capacity, that would do the same thing, ultimately, for you. Very similar. Not exactly the same thing. So mathematically, there is some difference between the two, but I wouldn't worry too much about that difference here. OK, good.

OK. So Andreeva, we have sales force, customers with potential versus current with some return rate. And here, you are not distinguishing between first-time customers versus those returning ones. So that has some implications in terms of formulations, but that's fine as well.

Backlog is fairly standard. Factories under construction, constructed. And you're calling these factories depreciating, [INAUDIBLE]. Is it a stock that you want to track? Do you do anything with it?

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah, it's not being used? Yeah, OK. That's fine. OK. That all makes sense. Did you see the sales force? Yes. OK.

RAHMANDAD:

And then Ali's model has the backlog, delivery delay, by the market, by the company. So you are taking delivery delay perceived by the market from delivery delay perceived by the company. That's an interesting idea.

I don't know. I think you could calculate them separately, I think as [? Katy ?] I think had done. But whether it is taken from the perception of the company is a little bit of a harder sell.

Because the company has access to a bunch of information that it's not going to directly share to inform the customers. Customers are using their own channels of information. So as such, I wouldn't take-- yeah.

Capacity, capacity under construction. That's a standard. And then we have the customer structure here. So this is current customers. They become potential. You pitch to customers. And then they can become current customers.

So you have the pitching process kind of very explicit. And that is what is coming from the sales force. So this is allowing you to separate the step of acceptance that is driven by delivery delay from the step of trying to influence pitching.

That's good. That's one way to kind of overcome that potentially a little bit more challenging formulation and keeping it very operational. Good. Sales force, recent revenue backlog-- and we saw the rest. OK. Great.

Finally, we have Jake's. So how come Jake's comes last? Daniels is not the first letter [INAUDIBLE] of it.

AUDIENCE: I think you opened it first.

HAZHIR Somehow, yeah. But I thought I had sorted things based on alphabetical order. OK.

RAHMANDAD:

So we have the backlog, work in progress, finished goods, delivered goods. So you have this additional detail on the delivery of goods just based on some delays. So the capacity is what does the production, but these delays introduce some additional complexity in terms of delivery delays. That's interesting.

So actually, let's now do a little bit of a deeper dive here and understand what's happening here. So units are all fine. So the story of-- people purchase. This goes into outstanding order backlog. Production capacity allow us to process this.

Now, you are combining kind of probably two things into production.

AUDIENCE: Yeah, my thought was like, you're going to be able to start work in progress-- basically run at full capacity if you need to just based on the backlog, but you can't go above that.

HAZHIR OK. So the equation here has a little bit of a unit problem for me. So I think of available capacity to be in widgets
RAHMANDAD: per year or units per year. But it seems you're using some definition of capacity that is in the units of units, not in the units of units per year. Can you tell what is--

AUDIENCE: Yeah. In my head, capacity is like-- it's not necessarily units per year, but you can have x amount of widgets currently on the product line basically. Like, at any given time, that is a unit that can be somewhere.

HAZHIR I see. So you are saying you have a number of factories, which you just call it as a factory. Then unit capacity per
RAHMANDAD: factory-- you're calling it unit per factory. So you are kind of removing time from the production capacity. You are translating it into work in process capacity in terms of number of units that are on the factory's floor.

AUDIENCE: Yeah.

HAZHIR And then you have a processing time of sort, time to process orders, that basically captures how fast you drain
RAHMANDAD: that capacity. So this could work. I think technically it is not wrong, but it is not the standard way we typically formulate these.

So the standard way is to think of capacity in units per unit of time-- so widget per year or month. This is our production capacity. That production capacity then would directly go into your production start as one of the constraints of that minimum function.

So it would be minimum of the production capacity and the outstanding order backlog divided by time to process order or minimum time to process order. Because then it would be minimum time to process order rather than time to process order.

The definition of this thing right now is kind of doing two very different things. So time to process orders, on the one hand, in your current formulation, is acting as minimum time to process order to put an upper bound on how fast you can drain or you can produce given how much backlog you have.

So even if you have infinite capacity, you cannot drain the outstanding order backlog with an infinite speed because you have a constraint in terms of number of items in the backlog. Then there is a separate time constant for how fast your factory produces the units it has in its working process, which is the way you were conceptualizing it in our first part of the conversation, going back to the available capacity.

So if you're saying available capacity, it is the total number of units on the factory floor, then it takes, for example, 10 days, or 10 months, or whatever to process that. You would divide that capacity by that processing time to get your average rate of outflow from the-- and right now, those two are conflated into this single parameter.

So that is one of the places where these two time constants should not be the same but are the same. So that's--

AUDIENCE: Or, yeah, I think the actual time to complete production is going to be the time to complete production after work in progress. It's literally just the time to go from order to get on the floor.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: But yeah.

HAZHIR So that would be-- so that's a little bit tricky because-- so now let's assume your production capacity is very
RAHMANDAD: small. Well, because it is very small, then you don't start production. But once you start it, it will go through this time to complete production.

So basically, time to process orders plus time to complete production is the total time for production in your conceptualization. So you have the degrees of freedom you need to basically get this to work. That makes sense.

So it's more kind of following the standard formulation would make it a little bit cleaner. But also, you don't then need all of these intermediate steps. Basically, here, you are adding two additional delays into the delivery.

And so this is kind of another important architectural choice. What are the time constants for my stocks? The stocks for finished good delivery, work in process delivery-- if they are relatively fast, then I don't need them. If I think they are fairly long-- so this is 0.2 months--

AUDIENCE: 0.2 years.

HAZHIR 0.2 years, sorry. This is 0.125 years. So these are in the order of a month or two. If my other time constants are
RAHMANDAD: kind of in that order, then it makes sense to separate them or be explicit about them.

If other time constants are a little bit longer, then it makes sense to bring all of them together into a single structure. So time to perceive delivery delay-- you have 0.25 years as well. So it's in the same ballpark. So maybe this separation is justified-- or reputation adjustment time a year for the outsiders.

OK. So I think this part is working fine, at least in the basic physics of it. Now you have shipping going into received products.

AUDIENCE: Yeah. You mentioned earlier it's sort of split between people and units-- it's not. These are just in terms of units. Like, the interest of market is just going to be units here. It's like a potential holder, not a-- yeah.

HAZHIR Yeah. So it would have been easy to make that transition, but you don't also need to if you are assuming each
RAHMANDAD: person is buying one unit. That's fine. And I think for this purpose, we are not changing that. So it's OK to have the same units.

So when you deliver something-- so this is market waiting for orders. This is really what I think should be deciding the delivery delay. So where does the delivery delay come from?

So right now, you have it from time in backlog based on orders outstanding in backlog divided by the production start plus time to complete production plus time to ship. So you're adding these three steps together.

AUDIENCE: Yes.

HAZHIR So that's probably the same as what you would do if you had market waiting for orders divided by received
RAHMANDAD: products. So that probably would give the same answer. It's a good thing to test that. Alexander?

AUDIENCE: [INAUDIBLE] ask-- back to the WIP and finished goods [? chain. ?] Shouldn't the latter two flows be constrained by capacity in some way? Because I'm thinking that-- let's say capacity is initially super high. So then you have a lot in the work in progress. And then, suddenly, capacity drops.

HAZHIR Yeah, absolutely. So this formulation is not fully consistent with those scenarios-- that it is assuming that once
RAHMANDAD: you are in the production process, the production capacity wouldn't change anymore for those batches. So that is, basically, the time constant for changing the production capacity is much longer than the time constant for changing the units in the production.

But it does create extreme condition problems, as you say. Exactly. And that's one of the reasons the standard formulation just says, have one place where production capacity is operational, typically at the very outflow of that backlog. And then don't worry about the intermediate steps. Yeah. So you're right. I think you can come up with extreme conditions like that that will break this formulation.

OK. So that delivery delay should work fine. You get the delivery delay perception here. Then you have a delay reputation that comes from that perception.

So there is a little bit of a question, what is this perception doing in factory construction sensitivity? So this is similar to what Ali had, which is there is a perception by company, and then there is a perception of delivery delay by the customers. But you are getting the perception of delivery delay by customers, which is this delay reputation, from perceived delivery delay by the company.

And these two, again, are a little bit different pathways information-wise. So I would perhaps have separate single delays, both of them taken from this current delivery delay but with different times.

I think in terms of the actual behavior of the model, they would be very similar. It's basically a second order delay versus a first order delay. So it's not going to make a big difference, but it is sometimes conceptually cleaner that way.

Now, yours has a little bit of additional change, that you're normalizing the delivery delay that is perceived by the company versus the desired delivery delay that they may have. So it's really kind of the ratio of those two that is input or-- so it's the minimum of the-- or wait, so delay reputation--

AUDIENCE: I just didn't want [? them ?] to go below zero.

HAZHIR Yes. Customer desired delivery delay minus perceived delivery delay divided by reputation adjustment time. So

RAHMANDAD: customer desired delivery delay minus perceived delivery delay-- that becomes-- so this is actually not--

AUDIENCE: Yeah, that's not right, is it?

HAZHIR It is not right. So let's throw out the minimum for us in our mind. This part really is not operational for most of the

RAHMANDAD: behavior. So what remains is the customer desired delivery delay minus perceived delivery delay. So it is closing the gap between perceived delivery delay and customer desired delivery delay.

AUDIENCE: [INAUDIBLE]

HAZHIR And then it takes it into this delay reputation stock. So it is integrating the difference between those two things

RAHMANDAD: with some adjustment time.

So integrating the difference between-- so if customer desire is always two months and perceived delivery delay and the actual-- or sorry, the perceived delivery delay is three months, it is integrating minus one months over time. It's, like, adding and adding to that stock. So that's not what you want to do. So this is not correct.

So what you need is simply, if you wanted to normalize, you would say, I'm looking at perceived delivery delay divided by customer desired delivery delay, or, minus that divided by something, as your indicated reputation. And then you would have indicated reputation minus delay reputation to inform the equation.

OK. So that's delivery delay. Factories-- this is kind of a one stock version. That gets a gap based on the desired factory. And desired factory is coming from-- OK. So this is--

AUDIENCE: Add together work in progress and the current backlogs, basically.

HAZHIR

Yeah. So it's looking at the current backlog. That is the work in progress, outstanding order backlog together.

RAHMANDAD: Why-- oh, yeah.

So it's a little bit tricky here. So this is going to make it harder for me to right now think about it. Because you're using this capacity only to drain this outstanding order backlog relatively quickly. But then you are using the work in progress backlog to expand the desired factory as well.

And that makes things a little bit harder to make sure it is fully consistent. So if for whatever reason we increase this time to complete production, we increase the work in progress backlog by a factor of 10, now your desired factory will go up by a factor of 10 even though you are not changing the purchase rate.

So now, at one level, that is correct because your time to complete production has increased. So you now need a lot more work in process capacity on the floor of the factory. So it is not wrong in that sense. But the way we think about factories, that's more confusing. So it is, again, kind of an indicator for using the standard formulation.

And then here you would be basically missing, OK, what is the effect of desired delivery delay, so to speak. Again, that is now embedded. So there is the effect of delivery delay on the top. But then there is the effect of desired delivery delay on what you want the desired factory to be.

That is now embedded inside these stocks because they change with the time to complete production and time to process orders. And the inherent assumption here is then that the desired delivery delay is the sum of these two delays.

That's all kind of hidden inside that formulation. It makes it less transparent for somebody who is reading them all. But I don't think it is wrong. I'm just thinking it can be simplified.

OK. And then you have capacity replacement plus something about closing the gap. But let's go into this formulation. So you can't remove factories. That's important. That's good. Capacity replacement plus factory gap multiplied by construction sensitivity divided by time to build new factories.

So construction sensitivity is coming from your delivery delay. And you have customer desired delivery delay versus perceived delivery delay. Now, this is a ratio-- so the ratio of perceived delivery delay to customer desired delivery delay is 1.

Then this multiplicative system will give you a quarter, a value of 0.25, which is your base sensitivity. You're going to then multiply your factory gap by that sensitivity. And then you would divide it by time to build new capacity.

So that is fine. It is closing the gap with a time constant. But if you notice, basically, you have two parameters that are double counting or just kind of redundant. So the factory construction sensitivity has a parameter which is multiplicative. And then you are dividing that by time to build new capacity.

And therefore, they are fully collinear. You don't need both of them. So as such, it's basically redundant.

AUDIENCE:

How would you get unit consistency? [INAUDIBLE] sensitivity effect on the time constant and then [INAUDIBLE]

HAZHIR Yeah. So I think conceptually, I see the appeal of having a parameter that changes the strength of this feedback.

RAHMANDAD: I probably would have used a power function rather than a linear multiplication.

And then the two would have had different effects. So it would have been that ratio of perceived versus customer desired raised to some power. That would probably do a better job.

OK. So I think this should work fine. And then you have this basic delivery here. OK. These are pretty meaningful with a few places that we could do better. Sales force is converting people who are interested. And the conversion rate depends on sales force outreach. This is kind of how many people they can reach out to.

AUDIENCE: The conversion rate doesn't depend on sales force average, but the sales does.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah, so you have the outreach. And then conversion rate depends on maximum, a reputation effect. And what

RAHMANDAD: else does it affect?

So if you don't have any total interested market, how would you shut off the sales path? So you have it in here. No, actually, you do have it here. OK.

So the question I was asking is-- the first order control for the sales outflow. And you want that to be dependent on total interested market. It is coming here. It is just not as visible.

So there is a maximum yearly outreach per sales person that is feasible versus your yearly outreach that comes from these people. And you are probably using some minimum function here. Yes, minimum of this yearly outreach and maximum possible per salesperson. So that's fine. That would do the job.

Now, again, the assumption that goes into this equation is important. So the assumption that goes into this equation is that, basically, if you don't have enough people in the market compared to the capacity of your sales force, the utilization of the sales force goes down linearly with how many people are in the market.

So that assumption basically says sales force people are not that capable of identifying open leads. That is, if the open leads go down, you linearly are bringing down the effectiveness of your sales force people.

Whereas, if there are just enough people, the sales force will be fully utilized at their 100% capacity. So that utilization function is kind of a little bit too extreme on both sides. That is, if I have just enough people who are interested in the product as my sales force capacity, it is a little bit unrealistic to think that the sales force capacity will be used at its maximum.

And on the other hand, if I have 80% of that number, bringing down the utilization by 20% may also be unrealistic. So some softer adjustment using one of the utilization functions that we have seen in other exercises as well would probably be a better idea here, even though this is not wrong. This is a good starting point.

So this would do OK. But there are better formulations there. But otherwise, this is fine. And it takes care of the sales the way you want it, again, with the caveat that this now assumes every new sales is very much the same as every repeat sales.

So that time to identify new leads versus go back to your old customers is usually very different. And therefore, it does make sense potentially to separate those two.

But this is a simpler formulation. And it's fine to have a simpler formulation. Just be conscious that you are making that choice. And I think some of the folks have an alternative here.

OK. I think formulation-wise this is a good summary of what is happening here. I assume you have not-- you have a fixed sales force fraction. Yes. So this fraction is fixed. And then we have the accounting that takes care of it.

OK. Let me just go to some random other--

AUDIENCE: [INAUDIBLE]

HAZHIR Yes. Go ahead.

RAHMANDAD:

AUDIENCE: [INAUDIBLE] Just going back to the capacity [INAUDIBLE] this is kind of what I was asking about early on. Yeah, so I had this issue where just something that I was considering was that factories take two or three years to build. And so if a factory is deprecated, you can't just immediately replace it.

HAZHIR Yes.

RAHMANDAD:

AUDIENCE: Right? So--

HAZHIR Yes. So that's right. So this is definitely a simplification that, in case of this exercise, I would have-- I think in the

RAHMANDAD: problem definition, there is a conversation about the time it takes to build the factories. So I think a better formulation would include the factory under development stock.

And in fact, I would also use higher order delays for depreciation of factories. First order depreciation is kind of a weird thing for a factory. The year you built a factory, you don't start throwing it out of your capacity. So at least a third order delay is due there.

Even for completion of factories out of the work in process, that also makes sense to have a higher order delay. So that would be probably a not cleaner necessarily, but a more realistic solution.

All right. So which is this one? So this is Kathy's. Let's take-- so manufacturing here, we had these units that are in the queue versus in production. We talked about-- it's a little bit similar to Jake's part, that you probably don't need all of that detail. But it could work just fine.

So the way you are doing it is also similar to Jake in the sense that the production start is gated by the capacity. And so this is one of those places that I'm now not sure what is happening. So the manufacturing capacity, you also have it in units rather than units per unit of time. So that's exactly the same issue that we had with Jake's point.

And again, I think that's deviating from standard formulations that will make some challenges. Now, it doesn't mean it is wrong. So let's look at what is happening with the-- so you are saying the units in production are stopping or kind of limiting what capacity remains.

Whatever is not in the production opens up a gate for starting production. And that gate is controlled by some minimum time to start production. And that minimum time to start production also gates the desired production start.

This is actually very similar to Jake's formulation, I think, mathematically. It has the same problems with-- yeah, I think it will work. It wouldn't generate any wrong results, but it is--

AUDIENCE: My question is, what is including this [INAUDIBLE]? Because I think the problem statement said, assume just a backlog, no work in progress. So [INAUDIBLE] just right on backlog. And there was no capacity in use and non-working capacity. So I didn't even think to do that.

HAZHIR Yeah. I don't know. What were you trying to do? What were you trying to get out of this formulation, Kathy? Do
RAHMANDAD: you remember when you were doing this?

AUDIENCE: Wow, [INAUDIBLE] yeah, I think I was just picturing in my mind what is happening. Units are kind of-- oh, these are the orders we have to fill. OK. That's different.

When do we get to start something? When we have an available slot for it? What are the slots determined [? by, ?] the capacity? So I think I was just really like taking it literally from that image in my mind. I wasn't, like, abstracting.

And then the capacity thing-- I think it was just a product of my brain. But I had it originally in units per month and more so standard. And then I started thinking about the slots idea and how that would kind be easy to implement. And so I changed it all last minute to units and just carry [INAUDIBLE].

HAZHIR Interesting. So that makes it a little bit more clear for me how you thought through it. And I think the process
RAHMANDAD: lesson out of that is, on the one hand, being operational-- just you try to be operational. Being operational is usually a good skill and good thing to do in the modeling because you have a tangible thing that you're trying to track.

But then it sometimes gets you too much into the weeds. And you may get lost in a model that is out of balance. That is, it has too much detail in some sector and is kind of missing other feedback, complexity parts that may be more important.

Now, I don't think you are missing something here on the other side, necessarily. But just that creates a trade off. There is really no easy solution to that. This is kind of a skill you have to build of, OK, let me go deep, have an operational story, but then ask myself, how can I summarize? Do I need all of that complexity?

And I think the time constants for these and what it buys you-- do I use, for example, these units in production differently from units in production queue? You're not. You're just basically adding up both of those to calculate a delivery delay. So why do I need--

AUDIENCE: Well, so I'm using them differently in that one of them is capacity constrained and one of them isn't. Like, there's no constraint on me taking orders. And so I didn't want to meter the process of taking orders. I wanted to meter the process of starting production.

AUDIENCE: Why are we taking orders [INAUDIBLE]?

AUDIENCE: I can't hear you. What are you--

HAZHIR So taking orders is units entering queue, correct?

RAHMANDAD:

AUDIENCE: Yeah, yeah. And I didn't want that to be capacity constrained because--

HAZHIR So that's not capacity constrained in a single stock. So think about a situation where, rather than having these

RAHMANDAD: two stocks, you just didn't have this flow. This was the one single stock. And the outflow here was constrained by the capacity, your total capacity. That's the solution that would sidestep these problems.

OK. Your average delivery delay is now calculated as units in production plus units in production queue divided by unit delivery. And then, what is the customer delay? Oh, that's just the [INAUDIBLE]. So that's the x. OK. That's fine. If it goes 0, it becomes expected [? delivery. ?]

AUDIENCE: Yeah, I didn't really know what was the best thing to make the x in that case, but [INAUDIBLE].

HAZHIR Yeah. So if your delivery rate goes to 0, basically the average delivery delay is a very large number. That

RAHMANDAD: basically says things are not good. So if you use expected delivery delay, that's not the best choice.

It is actually saying, this is the level that people will be happy with. So if ever this model touches the situation when there is no delivery, it will create delivery delays that are very attractive to customers. And as such, that's not the right choice.

Now, in your simulation, you may never see that. So you may not understand or see it in terms of the actual behavior. But when you are putting that equation, this is the thinking that you have to do?

AUDIENCE: But what if there are no units in production [INAUDIBLE]?

AUDIENCE: Yeah, so I was thinking if there are no units in production, it's because there are no orders. There's nothing going on. Therefore, there's no reason for the perceived delay to really deviate from the expectation.

HAZHIR So basically, then you have a 0 numerator and a 0 denominator.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR So that is a different situation. That happens rarely in this model because as long as--

RAHMANDAD:

AUDIENCE: It's just that the first--

HAZHIR Getting these stocks to be 0 is very hard because it requires somehow emptying anything that was in the stocks
RAHMANDAD: in the first place. Whereas, getting the flow to be 0-- that's basically, if you shut off production, it goes to 0-- now, in your model, not really. Because this also depends on the stock.

So this part of the delivery delay is always average completion time unless units in production goes to 0. But the way units in production goes to 0 is when you shut off this flow through, for example, not having capacity or something.

Anyway, this is OK. There's nothing bad here. And perceived delivery delay-- fine, you are using some smooth function, I assume. And smooth 3 might be an overkill-- just a simple smooth.

So a smooth 3 is information delay third order. You usually don't use it that much because it requires a measurement system that has multiple steps and then kind of maybe cobbled together with some additional perception of stakeholders. It is only in those situations where a higher order smooth function is justified.

Typical perception processes are very much first order delays, first order smoothness-- but not a big deal. I would put a box around things that have a smooth or delays so that, when I look at the diagram, I quickly see what are the hidden stocks in the formulation.

And then you have the delivery based reputation as just the ratio of these two things. And you are saying it doesn't go above 1. So that is, if-- it doesn't go above 1? Yes, doesn't go above 1.

So if this ratio is customer delivery delay expectation is much larger than perceived delivery delay, you want to filter out those situations and say, delivery delay based reputation is OK. It's 1. That's OK. Nothing wrong there.

But when I see that formulation, I also have in the back of my mind that you're basically removing information about situations where delivery delay is even better than what the customers want for downstream usage of this variable. And do I want to do that? There is always a question.

Now, I may want to do it because it simplifies my life to worry about the range. I know now that this is always between 0 and 1. So in all other places, I just use it with that assumption. I don't think about it.

But on the other hand, I'm stopping myself from having more nuanced formulations that may benefit from the fact that, OK, I now have a situation where I'm doing really well compared to what the customer is-- but a little bit of a trade off there.

OK. So manufacturing capacity fairly similar to Jake's, I think, in terms of having a single stock. Lifetime-- again, first order delay not the best formulation. Missing work in process-- not the best formulation, but OK.

And then indicated manufacturing capacity-- you are getting it from this units in production queue. So this is one of these places that things start to get messy because you're ignoring units in production. You're just getting it from units in production queue.

And then you're just generating the gap between the two. So you are not getting the feedback from the delivery delay that is perceived by the firm. So that's an important missing part of this whole thing.

Now, it is not that it is completely missing. Because when your delivery delay is high, these units in production queue go up. So as such, it is implicitly there. But this is just not the cleanest formulation.

It is also missing the replacement pathway. So this will create a steady state error.

AUDIENCE: [INAUDIBLE]

HAZHIR So if manufacturing capacity decommissioning is missing from the replacement or from the new builds, in the steady state, you always have an error-- error in the sense that you are not getting what you have desired. So manufacturing capacity is always above your actual manufacturing capacity. So that's bad stock management in general.

Is that part clear? Anybody has a question on that? Because that is not a trivial, obvious thing. But if you have built stock management structures, you have come across that thing.

That is, for the stock management to be internally consistent and give the desired values, you always need two different components. One is replacement of anything that is going out of the stock. The other is closing the gap between the desired level and the current level.

If you only have the closing the gap between desired and current level, you will have what we say is a steady state error. It means in the steady state, the outflow is not replaced.

And therefore, there should be a gap between the desired and actual to generate enough inflow to equate the outflow. So therefore, by definition, your desired level will always be above your current stock in the equilibrium. And that is just not right. So that's important. Hassan?

AUDIENCE: In the text of the question, you first suggested that we look more into the pressure that these [INAUDIBLE] disclaimer, I didn't. I went for the [INAUDIBLE] and I knew that I didn't [INAUDIBLE] but that doesn't apply to when we're formulating based on the pressure in the company.

HAZHIR Yeah. So the pressure based-- kind of the intuition there is that the firm is creating an anchor based on their current level of capacity and then decide whether to expand or contract. And if it is expanding, it is coming from the pressure to expand.

So that anchor and adjustment is a different formulation for stock management compared to replacing what is coming in and adding the--

AUDIENCE: The pressure formulation based on the intensity of change that the company actually does based on that pressure. There is a chance that they will have--

HAZHIR They will overshoot.

RAHMANDAD:

AUDIENCE: Yeah, or they can't keep up with [INAUDIBLE].

HAZHIR Or they can't keep up, absolutely. So that pressure-based formulation alternative-- first of all, even in that one, you do need the replacement piece.

If you don't have the replacement piece, it will create a steady state problem. Because there's always kind of an outflow. And the inflow is just always trying to catch up. So there will be a gap between the desired, which, the desired can come from your current level with the pressure.

But still, there will be a gap. So as such, that is also having the same problem. It's just that, where does the desire come from? Does it come from the customer orders or something along those lines? Or does it come from the delivery delay perceived and the anchor being current capacity?

I think both of them are pretty legitimate. And in fact, the behaviors may not be that different. In fact, anchoring to what is the current backlog or current recent customer order rates is less prone to big swings. Because if you have a very strong or very weak response to that pressure, then your desired levels will not be matching or will be overshooting what the customers are asking. And that creates instability.

But I asked for that formulation exactly because of that challenge. That is how Forrester formulated it. And that is one of the reasons you get kind of very unstable behaviors in the market growth models.

If you went with the more standard stock management, it is actually a little bit more stable. Now, I haven't done the full comparison there.

AUDIENCE: Could you explain again why it's more unstable if you do it with delivery [INAUDIBLE]?

HAZHIR
RAHMANDAD: So when you are doing it with the-- there is an impact of delivery delay on expansion. So your desired factory level would be your current factory level multiplied by some effective delivery on capacity expansion. That effective delivery on capacity expansion is dependent on some parameter or some table function. But let's say a parameter.

And it can be sharper response or slower response. And that sharpness is not controlled in any direct way by how big is your delivery delay or how big is your customer demand currently compared to your capacity.

So ultimately, if your customer demand is in widgets per year or widgets per month, and your capacity is also in widgets per month, you want the two to be matching with the potential extrapolation that demand is growing. So let me look forward a few months based on how long it takes to create capacity so that I'm matching the demand I expect to have six months or two years from now, whatever is your work in process delay.

That is kind of the more clean, logical approach, in the sense that you have a anchor that directly takes you to serving the customers exactly at the rate that they are going to come in. You can add a buffer or whatever you want.

But the alternative doesn't provide that direct mapping. And therefore, you can be too fast in expansion or too slow in expansion.

AUDIENCE: Oh, wait. Hold on. I thought you were saying that the delay formulation's anchoring is what may lead to more instability. Whereas, the alternative that you're saying is, this is more stable, yeah.

HAZHIR
RAHMANDAD: The one that is more stable-- or not necessarily stable, but cleaner in the sense that it is more rational-- is the one that gets the desired production rate from the expected customer order rate and then from that calculates the desired production capacity.

AUDIENCE: Which is what Kathy's doing, right?

HAZHIR
RAHMANDAD: Which is what Kathy is doing, with a caveat that Kathy is not taking it from the units entering queue, which is the demand. She's getting it from this stock here and then turning it into a stock thing. Because this manufacturing delivery is also not in the units of widgets per month. But it is in the units of units or widgets. So that creates a little bit additional messiness here that I can't mentally simulate fully.

AUDIENCE: So two more technical questions. So first is that, because this firm is producing to a backlog, they have some desired shipments, which is the backlog divided by some desired shipment time-- again, with a single stock [INAUDIBLE]. So what is the difference between using that versus the order rate?

HAZHIR It should be about the same. So basically, you do the backlog divided by delivery delay. You get the average
RAHMANDAD: level of the orders coming in. So as such, it is a little bit more stable a signal. So if you have a lot of ups and downs, that's a better formulation. For a deterministic model that doesn't kind of have noisy things, then it doesn't make a difference.

AUDIENCE: And then my second question was that Jake kind of did both, actually. Like, he determined the indicated capacity level by the backlog level or something. But then the time was adjusted by this pressure due to delay essentially. Because he had this [INAUDIBLE].

HAZHIR Yes. So basically, he was thinking of closing the gap to be more sensitive or less sensitive based on the delivery
RAHMANDAD: delay that is observed. And that is actually a nice formulation in the sense that, you are closing the gap no matter what, but how fast you're closing the gap is partly driven by how bad the delivery delay situation looks like. So I think I like that, as it kind of conceptually captures a bunch of these problems we are trying to solve.

OK. I think this is good conversation in this model. Just a quick thing-- so I assume you are using a fixed sales force-- not fixed, fractional sales force.

AUDIENCE: Yes.

HAZHIR OK. So that's fine. That's fraction of revenue. I'm not going into through the rookie dynamics. I assume they are
RAHMANDAD: coming from the standard formulations in Stearman.

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah. Good. Let's do a couple more models. Let's see. Who's is this one? Ann.
RAHMANDAD:

OK. So again, we have the facilities, first order draining-- not the best alternative, but OK-- new construction, coming from gap from threshold.

OK. So the new construction-- let's look at the equation. This is a little bit-- so you have the total facilities divided by time to expand multiplied by effective delivery delay on capacity expansion. Ann, can you explain what you were thinking in formulating it this way?

AUDIENCE: Yeah. So I misunderstood the prompt. But I was thinking that just because there's a-- I was thinking that the decision to build new facilities depends on your particular threshold of customer dissatisfaction because of the cost in building new facilities.

So even though you're not meeting the customer expectations, there's still that delay until a certain threshold has been exceeded. And then they decide to create new buildings. And they just increase by, like, a percentage based on the current facilities that they have.

HAZHIR Yeah. So this is not really doing what you were thinking or what you need to do here. Because basically, this one
RAHMANDAD: is creating a very strong first order reinforcing loop that says, the more facility you have, the more you will build, with some attenuating effect coming from effective delivery delay on capacity expansion.

So if your total capacity is very high, then probably this delivery delay effect gets smaller. And at some point, it may slow down or even stop. So this is a little bit additional complexity here to understand.

But this is kind of $1 - e$ to the power of something. So it's probably going down with more gap in delivery delay. $1 - e$ to the power of minus-- so it goes up like this. Yeah.

So if you don't have any delivery delay, it can go to 0. If this goes to 0, then you wouldn't be building new capacity. So it may look like it is working, but it kind of works in a very weird way that doesn't directly map into useful real-world constructs.

So the solution, again, is basically a factor for replacement of death to buildings and a factor for adjusting toward your desired level. So there is a desired level of capacity minus facility minus current facility. And that desired facility could come from your current facility as well multiplied by some factor that is expanding the facility based on delivery delay. So something along those lines might be what you need to have here.

Backlog part fairly simple-- and simple is good here. Just have new orders coming in. And you have the orders versus customers. So you have the change of units here. That's fine.

And then the delivery of units is determined by what? Backlog divided by delivery delay? Oh. Oh. Huh. OK. Yeah, this works.

Ann, this is an interesting piece. What you have is right, but it's not following the classical formulations. And it creates a little bit of a confusion for me when I first saw it.

So typically, we would have the delivery to be regulated by the production capacity. So it would be the minimum of production capacity and maximum delivery rate. And that maximum delivery rate would come from backlog of orders divided by a minimum time to deliver.

So that would be your order delivery. Then backlog divided by order delivery gives you the delivery delay. The way you have calculated it is the other way. That is, you have calculated the delivery delay using production versus backlog. And you have basically divided the backlog by production capacity.

AUDIENCE: [INAUDIBLE] idea was like there's a fixed capacity for each facility. And as the backlog increases, then there's a delay in delivery to customers.

HAZHIR No, I'm not saying it is wrong. I'm saying this is kind of not the typical way we formulate this. And the way you
RAHMANDAD: have formulated it also kind of takes away this constraint of maximum delivery rate coming from not having enough in the backlog.

Yeah. And again, it doesn't make a big difference here, but it is just a little bit non-standard formulation.

AUDIENCE: Isn't deliveries in this case always equal to production capacity [INAUDIBLE]?

HAZHIR So, Yes, deliveries will all-- no. So when the backlog goes to 0-- but then you're dividing it by this delivery delay
RAHMANDAD: that is 0. Then it is always production capacity. And therefore, you don't have first order control. You will get problematic behavior. You're right.

Ann, what Alexander noted here is that when you multiply your backlog or divide your backlog by your delivery delay, remember that delivery delay is already your backlog divided by production capacity. So the backlogs cancel out each other. And basically, your order delivery becomes production capacity.

And therefore, you wouldn't have the first order control. That is, you wouldn't have a limit that avoids your backlog going negative. Now, in your formulation, basically the model will crash because you will get to a backlog of 0. And then you will have a division by 0. That will be what will happen.

So, yes, use the standard formulation. That's the summary of this case. Then we have potential customers becoming likely customers. And there is kind of effective delivery delay on conversion rate.

So the conversion rate-- these are people who have learned about the product through the sales channel. OK. So the conceptualization here, Ann, if I'm understanding it correctly, is that the main effect is happening through this conversion rate. And once people have converted, then with the time constant they order. So this is your order rate, customers placing orders.

And then orders are delivered. They become customers with products. And after a while, they go back and buy it again. So--

AUDIENCE: Yep.

HAZHIR --you are not using the sales force to basically to do two things. One is to convince these people that have
RAHMANDAD: stopped using the product to come back and buy it again. So this step is happening automatically. Secondly, you are adding this delay between the time people are contacted and convinced by the sales force until they decide to put an order.

Now, that second one is fine. I think conceptually that's not a problem. The first one is more problematic. You do need sales force to also convince people who need to do a replacement purchase.

AUDIENCE: OK.

HAZHIR OK. Let's see. Anything else here? So sales force-- you have the replacement time. Oh, time sales force to be
RAHMANDAD: fired.

AUDIENCE: So this part [INAUDIBLE] but I think the idea was that there's a percentage of revenue reserved to pay the wages of sales force.

HAZHIR Uh-huh.
RAHMANDAD:

AUDIENCE: And if the cash available is too small, then they would fire some members of the sales force so that they always have that money to pay them. And then if the cash builds up again, they would hire [INAUDIBLE]. I didn't have time to formulate that.

HAZHIR I see, I see. So basically, you're kind of having money that is put aside for sales force. And if you have--

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah. And if you have enough money, you are keeping your sales force. Otherwise, you're firing them.

RAHMANDAD:

AUDIENCE: Yeah.

HAZHIR And then you have an exogenous hiring rate. You're just hiring people. So--

RAHMANDAD:

AUDIENCE: No, that part is not complete. I was supposed to replace the people fired as well when the cash builds up, but I didn't have time to put it in. But that's the idea.

HAZHIR So it is somewhat convoluted. Mostly, people control their stock of employees through hiring. Firing does

RAHMANDAD: happen. So that's OK to have a firing that is also determined based on money you have.

But adding this stock of cash that is reserved for salaries is kind of not adding that much value in terms of, it kind of just adds a bunch of parameters and additional structure you need to manage. Even having explicit hiring and firing may not be the most effective way.

You can just have an adjustment of sales force using a first order adjustment process. And then the desired sales force can easily come from your budget for the sales force. I think that's what others also had in this formulation. That's much simpler.

If you think people are less eager to fire people than to hire people, which is part of the real organizational dynamics, you can make it an asymmetric delay and adjustment so that, when the desired level of sales force is higher than the current level, you adjust it much faster. When the desired level is lower, then you adjust it more slowly.

In the extreme, it would be how long people typically stay in your company, which is for the downward adjustment. That is, you just let it happen through natural turnover, not through actually firing people. So that's a simple way to take care of the hiring and firing, even if they are asymmetric in terms of adjustment.

AUDIENCE: I think my confusion was like, if there's a fixed amount that is allocated to the sales force, then how do you control if that amount is [INAUDIBLE]

HAZHIR So what's the fixed amount unit? So what's the unit of what is allocated to sales force?

RAHMANDAD:

AUDIENCE: Maybe a dollar value per time period as a percentage of the revenue.

HAZHIR Great. So let's say dollar per month. So I have \$1,000 per month. I mean, \$1,000-- who comes to work for me for that price? But let's say \$1,000 per month of budget for my sales force.

RAHMANDAD:

And then each salesperson, now that we are so cheap, is willing to work for \$50 a month. So what's the number of sales force I can have?

AUDIENCE: [INAUDIBLE]

HAZHIR So that's 20 sales force. You're adjusting your current stock towards that desired. You take care of all of that. You
RAHMANDAD: don't need to worry about another stock that accumulates that \$1,000 and then tries to spend it. It's just too many things.

OK. Good. I think it's a good time to take a break-- 10 minutes. And then we come back, look at a few more models.

So one very minor thing here is, you are starting the DELAY3 function without initial. So it is initializing it in equilibrium. But the stock here of production capacity, PC, is starting with initial PC.

So this creates an internal inconsistency. So this is a little bit kind of subtle there. Because in this link from PC completion to PC depreciation, there are three stock variables hidden behind the scenes. And they have their own initial value.

The initial value used there is basically the PC completion rate at the beginning multiplied by facility life divided by 3 for each of those stocks. That's what is being used in the back end.

But what you're using as the sum of those three that should be the production capacity is initial PC. And there is no reason here to automatically expect these two to be the same. And that can create weird, unexpected behaviors.

So I would have it as a DELAY3 EI with initial condition and set the initial condition to be your initial PC divided by facility life. Then you're all set.

AUDIENCE: Can I ask how that takes care of the issue? Because PC divided by facility life only happens for the initial time step. So after you drain whatever fraction is there, then you go back to just only-- like, do you see what I mean? You're still draining-- I guess I'm just asking is--

HAZHIR So I'm trying to get the production capacity, PC, to be exactly the same as some of those three initial stocks that
RAHMANDAD: are hidden behind this link. OK? Some of those three initial stocks would be whatever I give it as the initial outflow, initial value of the delay. The initial value of delay is the outflow, in this case, PC depreciation.

So it would be that initial outflow multiplied by facility life. So by setting that initial value to be initial PC divided by facility life, I achieve this equivalence.

And once I started from the equivalent value, they will remain equivalent all the way through because the inflow and outflow of production capacity PC is coming from this-- I mean, the outflow is coming from this delay. That inflow is also this initial of the delay. So then they are always going to be the same moving forward.

OK. So WIP first order delay-- that's fine. PC building is coming from-- OK. Let's see what is happening. Desired PC building-- this is probably max of 0. And desired PC building-- something that you always want to make sure is in place.

You have an adjustment for WIP. You have indicated expansion to meet demand based on the current production capacity.

OK. So let's see what is happening here. So you're looking at the total need divided by current value. So this is desired stock minus stock. So this is a stock adjustment.

This stock adjustment plus the replacement-- and what is the expansion commitment delay you have here, Alban? Do you have a kind of a story there?

AUDIENCE: So I was trying to capture, you have decision making time. Like, you don't come into inspection immediately [INAUDIBLE].

HAZHIR OK. OK. That's fine. That's conceptually correct-- maybe an overkill here, but that's OK. And you were missing
RAHMANDAD: that unit. OK. Or maybe I deleted it somehow.

Then desired completion is just the sum of these two. And then you add the adjustment for WIP. So this is fairly standard.

So the key question is, where does the indicated total PC need come from. You are looking at the excess delay and the current.

AUDIENCE: So you're just scaling up your production capacity but the [INAUDIBLE].

HAZHIR Yes, with some delay effect. And this excess delay effect is coming from the actual delivery delay versus desired
RAHMANDAD: delivery delay. So this is a fairly rapid perception of the delivery delay.

But because you have this additional delay for expansion commitment, that delay is kind of captured there in a sense. So we didn't have an explicit separate delay for perception of delivery delay by company. But instead, we have an adjustment there.

And this excess delay is just a ratio of these two. Similar to Kathy, you are limiting it to a floor in this case because you are using the actual versus desired. And you only care when the situation is that things are getting bigger.

So this is kind of an important question here-- whether you want to allow for reductions in the capacity. And in this model, I would want to see reductions in capacity, because you could have a situation where the steady state, long-term replacement is much lower than the growth phase replacement plus new purchase.

And therefore, you want to include a pathway for reductions in capacity. Whereas, if I'm correct, this model right now doesn't allow for reductions in capacity.

AUDIENCE: Right.

HAZHIR So is the logic clear how I made that conclusion? So let me backtrack. So the indicated total PC need is current
RAHMANDAD: production capacity multiplied by this expansion factor coming from excess delay.

If excess delay never goes below 1, this indicates that total production capacity never goes below the current production capacity and therefore never can go down in terms of the desired value. So that's why I inferred that, by this formulation, you are making it impossible for the production capacity to go down. And that's not what you really want. That takes away some flexibility you do want to have.

OK. So that's the capacity management backlog. Pretty straightforward-- sales. And then you have the delivery taken out. And the delivery is dependent on the capacity utilization. You're using a very similar formulation as we had in the widgets model with a little bit of more complex formulation here.

AUDIENCE: It's a fuzzy mean [INAUDIBLE]

HAZHIR Yeah, that's the fuzzy mean thing that Hassan proposed a few weeks ago. Yeah. Cool.

RAHMANDAD:

AUDIENCE: The only downside of that is-- and this is what I was struggling with that formulation. Let's say, if the desired production rate is smaller than the capacity, the company can decide to deliver faster than it's desired delivery to gain reputation. But that formula doesn't allow that.

AUDIENCE: If it goes above that 45-degree line, [INAUDIBLE].

HAZHIR Yeah. So that formula by design wasn't going above 45-degree line. It is actually easy to have alternatives that

RAHMANDAD: go above 45-degree line. But ultimately, what that will do is that the actual delivery delay will never go below desired delivery delay in this formulation. And therefore, this excess delay actually would never go below 1, even if you didn't put the max function.

And then that creates this issue of not tracking when the demand is falling. It wouldn't be able to bring down the capacity even if you removed that maximum that we talked about.

So you see this is kind of a little bit, again, subtle. But this goes back to the conversation we had about whether using a pressure to drive capacity-- so you are here using a pressure. The pressure is coming from that delivery delay-- or using the recent order rate as the driver of desired capacity.

Now, I told you to use pressure just so that we can have these conversations. But it is also showing the failure modes built into that pressure. Now, the Forrester version does bring it down as well. So he doesn't use this function. He uses a table function. And that table function allows for reducing the current capacity, which this one doesn't allow for just by these formulations.

But I want you to be sensitive to how these assumptions in each equation has reverberations down the road. So think about those as you walk through your formulations. OK. Good.

So we have the cells. And now you have the potential customers. They become new customers. And then you have the return. And depreciation and return is the same. So that creates sales. This also creates sales.

But here, again, similar to Ann's model, you are not accounting for sales force being needed for attracting returning customers. So that's an assumption that might be a bit strong here. Now let's look at the capturing of new customers using the current sales force.

So you have a number of pitches. And that number of pitches can come from productivity. That productivity is normal productivity and some max productivity. And max productivity depends on the ratio of current customers to the sales force. So that's--

AUDIENCE: Sales force times--

HAZHIR Time to pitch.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR So it's similar to that-- yeah. So this is logical. The constraint works, creates the effect. But it is not a flexible

RAHMANDAD: effect because you don't have free parameters to account for non-linear responses. Yeah.

And then productivity is the minimum of these two guys, which goes into number of pitches. And then the conversion rate, given the number of customers you are pitching, is determined by this effect of excess delay.

So right now, you don't have any delay perception for the customers here, unless there is a delay built into this equation, which shouldn't be. Yeah.

So I would include an explicit delay. So right now, the excess delay is coming directly from the customer service side. And that takes time to be perceived in the marketplace. So that perception delay is important to have.

Yeah. And then the power function here does fine. So you have higher excess delays. You will get lower conversion rates. And that should be OK.

If you had lower excess delays, which you can't here because of two different reasons we talked about, then faster conversion rates become feasible here. But you have the maximum function of these-- no, you are multiplying them.

So that's a little bit of a question. That is, if you have close to 0 delivery delay-- that is, you remove those constraints that make it hard to reduce your delivery delay below current levels, if you have very fast delivery-- your conversion rate can go to infinity. It can go very high in this formulation. And that's just not realistic.

So in fact, conversion rate should be conversion probability. So it is really a matter of a probability. You want it to also be dimensionless, I think. Yes, it is dimensionless.

So if you call it probability, then it should never go above 1, which means you need a more nonlinear function here to account for that. But then it works fine.

Good. So then we have the sales force. You have the desired sales force, adjustment time based on wages and budget. Budget comes from revenue. It's all good. If you want to have a more serious cost-benefit part, you would account for the cost of your operations. That is, your production capacity may have fixed costs.

You can think about these sales to be just not product price but product profit so that this accounts for the variable cost of production. But still, you would have the fixed cost of production and the cost of building of the work in process-- yes.

So where does that cost go? Yes, this is here. So you have it in the profitability. And you're getting it out of the revenue. That's OK. That's OK. Yeah. And then-- yeah, [? Sally? ?]

AUDIENCE: So how do we decide with these types of models if the decision to expand the capacity should come from the delivery delay or the production capacity that we have for the profitability?

HAZHIR So typically, profitability is a constraint on expansion. So you have a desired level of production capacity. And

RAHMANDAD: you go through whatever formulation you're going. And then you can have another constraint that says, I don't have enough money to build, or, I can't convince the banks to loan me enough money because I'm not very profitable.

So that would be the way I would capture it. That is, my total production rate could get affected by availability of financing based on a function of profits.

AUDIENCE: Yeah.

HAZHIR Thank you.

RAHMANDAD:

AUDIENCE: Could you go over again why you need that additional value?

HAZHIR Sure.

RAHMANDAD:

AUDIENCE: Because I don't quite--

HAZHIR So let me give you an extreme condition. So let's say initial PC, I put it as 0. OK? Now, PC completion at the

RAHMANDAD: beginning is a positive number.

And therefore, the initial value of PC depreciation is also a positive number. OK? Because this formulation is just simply DELAY3 of PC completion. And when it is DELAY3, it starts from equilibrium, which means it starts from the initial value of PC depreciation being equal to PC completion. OK?

So now I have zero production capacity, but I have positive capacity depreciation. That's just not right.

AUDIENCE: Yeah. So I see why this past [INAUDIBLE] but I'm a bit confused as to why the value for the initial is PC divided by facility length. Because even if you were to have all of these stocks laid out, that outflow at the end is that figure divided by 3, right? So that's-- yeah.

HAZHIR So let's for now ignore the order of the thing. So in a steady state, the PC depreciation would be PC, or initial PC,

RAHMANDAD: divided by facility life. Correct? That's Little's law. So stock divided by the time constant is the flow in equilibrium.

And that's all we are using here. That is, the initial value of the outflow should be the equilibrium value so that then that's how Vensim will operationalize it inside its hidden three stocks, or 10 stocks, or one stock depending on what the order you're using-- will be that total divided by the order of the stocks.

You don't need to worry about that order of the stocks. Vensim will take care of that. The sum of those stocks will always be what you get in the initial PC once you make the initial outflow to be what it needs to be here.

AUDIENCE: So Vensim actually uses that outflow to calculate the value of all of those stocks?

HAZHIR Yes, that initial outflow is what it uses to calculate all of those stocks.

RAHMANDAD:

AUDIENCE: [INAUDIBLE]

HAZHIR Yeah, and it does that by equally distributing it across all of the initial stocks. OK. So I think the basics are all in

RAHMANDAD: place with all of the minor caveats that we talked about here.

Who likes us to look at their model? Let's kind of open it up for volunteers. Sure.

AUDIENCE: It's not good.

HAZHIR It's OK. We are not--

RAHMANDAD:

AUDIENCE: [INAUDIBLE] equilibrium. There's a lot of really bad areas, but--

HAZHIR That makes it more fun--

RAHMANDAD:

[LAUGHTER]

--to critique. Not fun, more educational. OK. So you have the facilities, factories. You have first order delay. We talked about that. And then you have the construction rate based on the factory adjustment, which is comparing the authorized or desired.

And the desired is coming from something we'll get to-- versus the current level with an adjustment time. And then you add the factory construction rate so that you don't have the steady state problem that we talked about. That's all good.

Again, this is ignoring the work in process inventory of factories. And the units for factories are in--

AUDIENCE: Factories.

HAZHIR --factories. OK. So typically better to make it in the units of production capacity so that it is easier to think without

RAHMANDAD: worrying about the parameter that converts them, but it's all right.

AUDIENCE: Yeah. [INAUDIBLE] obviously discrete amounts. So then I did integer factory, which is wrong now that I think about it more.

The idea was, I was like, oh, well, when I'm building capacity, if I have 1.5 factories, I only have 1 factory. Then I wasn't taking into account, as the factories depreciate, I still have the [? local ?] factory [INAUDIBLE] integer down to 0.

HAZHIR Yeah. So integers are hard to deal with. Don't get into the integer stuff in Vensim. I mean, Vensim is not the right

RAHMANDAD: tool. You can do it. It's just kind of a headache.

So I wouldn't touch integer constraints because then you have to be really consistent. Like, the inflow needs to be integer. The outflow needs to be integer. And it's not worth it. So don't worry about that.

But let's for now put that aside. So now the authorized number of factories-- you're starting at equilibrium. So the initial number is the same for both of them. That authorization is coming from some pressure to expand and some time to authorize. OK. I'm not following this yet.

AUDIENCE: So the idea there was like, here's some delivery delay. They have the promised delivery delay and then some-- the reference delivery delay-- I don't actually know if it makes any sense, but the idea of the company itself is OK with the delivery delay actually getting this much higher than the promised delivery delay. And so then there's going to be like some magical pressure variables to come out of that.

HAZHIR But how do you get the units for now? So let's focus on that. So the authorized number of factories in factory-- so
RAHMANDAD: changing authorization is factory per month or year, but-- per month. And this one is pressure to expand capacity multiplied by pressure to factory conversion.

AUDIENCE: The idea was just that there's some number that would decide how many factories they want to [INAUDIBLE] but the actual pressure number doesn't make any sense. This isn't based in any real idea.

My idea was just that, oh, some delivery delay is happening. And it's somewhere within or without the reference of how OK they are with the delivery delay being, and that that whether it would be actually through a table or through something else would be converted from that pressure into how many factories they want to build. And then from there, you can actually--

HAZHIR So the thing that you are doing here is a little bit tough. Because you're trying to start with the right number of
RAHMANDAD: factories and then just expand that, accumulate on that or potentially even reduce-- I haven't looked at the pressure, whether it goes negative or not-- without any response or any feedback about how many factories already you have. Because there is nowhere here a feedback from the current number of factories.

So it is not anchored in the current state. It is only accumulating over the starting point of the factories. You see what I'm saying? So--

AUDIENCE: Oh, when the factories depreciate, [INAUDIBLE]

HAZHIR It is not taking that into account. If the need for factories goes down significantly-- it is basically kind of-- does it
RAHMANDAD: call it dead something navigation? That is, you start from a point--

AUDIENCE: Dead reckoning.

HAZHIR Dead reckoning. It's kind of dead reckoning. You start from a point, which is the current level of factories. That's
RAHMANDAD: OK. And then you just accumulate into that based on some pressure. But you're never getting feedback whether this number is close to some underlying desired value that should be driving it or how far you are from the current factory. None of that comes into play. So--

AUDIENCE: But isn't the desired amount this--

HAZHIR So the desired amount is going to change the number of factories. So there will be connection between the
RAHMANDAD: number of factories that you have and this authorized number. So those two will remain tied to each other.

But this authorized number is not tied to anything. It is only being accumulated using some external pressure. And therefore, it is a little bit tough to keep it well grounded. That's the core challenge you're facing.

Now, it may work just fine in the sense that, if the signal from pressure to expand can go both positive and negative, if it overshoots, it brings it down. If it goes down, it brings it up. But typical formulations will make this kind of a fractional effect.

That is, OK, if I have a number of factories, I will multiply that by this expansion factor so that I can grow fractionally, so that if I start with one factory and my rate of change in this change in authorization is in the order of 0.5 factory per year, 10 years from now, now I have 100 factories.

It doesn't make sense to change my factory by 0.5 per year. I now want to actually be able to change it by 50 per year maybe. That is not possible in this formulation because the scale of these three things coming together is always constant based on some dimensionless thing from here. OK.

AUDIENCE: [INAUDIBLE]

HAZHIR Could you speak up a little bit?

RAHMANDAD:

AUDIENCE: Sorry. So isn't the pressure to expand capacity exactly the variable we're looking at? Doesn't that depend on delivery delay [INAUDIBLE]?

HAZHIR Sure, sure. All of that is correct. And therefore, there will be a feedback, but--

RAHMANDAD:

AUDIENCE: There will be feedback [INAUDIBLE] right?

HAZHIR It is not proportional-- so the adjustment is not proportional. And therefore, the feedback remains very linear-ish.

RAHMANDAD: So if the scale of operation is not changing, this could work OK. But it is blind to the scale of operation.

So if you end up with a larger scale because you are dealing with, for example, an exponential growth, it just cannot catch up with that. That's the challenge, especially with an exponentially growing demand, which is the case here. This becomes a very tough bottleneck.

It just doesn't allow the capacity to catch up. And then you fall behind and behind. Now, you don't fall super behind because your delivery delay now goes up so much that you can't grow exponentially. That creates a kind of a linear growth type of a dynamic. That would be my guess, that this kind of creates that. We can simulate it.

AUDIENCE: [INAUDIBLE] so what's the lesson? The lesson is you want comparable units when you're doing this type of [INAUDIBLE]?

HAZHIR So the real lesson is, if you are creating a desired level for anything, you want it to be anchored to something

RAHMANDAD: current, whether it is the current capacity that you want to anchor to or current demand that you want to anchor to. But anchor that desire to something current. Otherwise, expecting the dead process to get that thing to the right place is too much to ask from your models.

That's from your formulations. Because the scope of these adjustments are not tuned for different scales of operation. You just multiply everything in this model by a factor of 100.

The model will not scale because this part of the formulation for changing authorization-- nothing changes there. It's still in the units of half a unit or one unit per month no matter what the scale of operation is. That's kind of the challenge.

OK. Delivery delay-- fairly standard. We have the max completion versus the potential completion coming from your factories. Let's just skip the integer stuff here. Then you have the purchase rate. And then you-- purchase to tasks.

AUDIENCE: Well, it's just assuming that the-- per customer they're buying [INAUDIBLE].

HAZHIR Yeah, that's OK. You're just taking care of the units somehow. Then you have the sales force and the customers.

RAHMANDAD: So you have customers. You have purchase rate. You have depreciation. This purchase rate is coming from reputation.

So you are kind of doing similar to a few others that we saw, that there is a process to get customers into your orbit of customers. And then once they are in, they will continue to buy from you. As soon as their product life ends, they go into this interested customers with a delay. They will purchase, but that is bounded by your reputation.

So this should be OK. It's a little bit tricky kind of how the reputation is working here. So if you have zero reputation, yes, this shuts off.

AUDIENCE: [INAUDIBLE] no interest.

HAZHIR Yeah.

RAHMANDAD:

AUDIENCE: But the formulation was incorrect. But that was the idea.

HAZHIR Yeah. So the formulation-- the bigger part that is missing here is the interested customers going into it. So the
RAHMANDAD: purchase rate should not be independent of interested customers. This is interested customers divided by time to purchase. And it should be a short time constant. Then you can adjust around that with the reputation.

OK. And then gaining interest-- there is a max customers visited. That's kind of the same idea that we had in other models.

AUDIENCE: This is where I got confused, one, because of the revenue constraint. But then, secondly, I think it wasn't something I needed to do. But it felt like there shouldn't be more sales force people than there are [INAUDIBLE] customers.

HAZHIR So these things depend on that conversion rate. So you actually could have 10 different sales force people

RAHMANDAD: working on a single customer. If your single customer is the US government and you are, I don't know, Boeing trying to sell a single missile to the government, you may have a whole army trying to sell that single unit. So that is just a productivity factor.

OK. So let's look at these sales force formulations. So attrition is fine. You have hiring that comes from the adjustment of sales force. That adjustment is based on the desired sales force. So what's missing here?

AUDIENCE: The attrition.

HAZHIR So attrition needs to be accounted for for the hiring rate. And then you would have basically attrition plus
RAHMANDAD: adjustment max of 0 and that thing. Otherwise, you have a steady state error.

Once you have your sales force, you have max customers visited based on the--

AUDIENCE: This is a little bit confusing for me.

AUDIENCE: Yeah. I just started getting negative customers at one point. And I was trying to figure out why. I thought that maybe it was that I was somehow visiting more customers.

HAZHIR Yeah. So basically, you need the minimum. This is fine. But then the max customers visited and actual customers
RAHMANDAD: visited-- the terminology is a bit confusing. So this is kind of potential customers visited based on your sales force size. And this is the max customers visited based on the potential interested customers.

And the equation for max customers visited should simply be potential interested customers divided by minimum time to visit customers or something like that. So that's fairly standard. Then you can use the-- and back to the same point we had with Alban and a couple other, this doesn't give you flexibility to have a non-linear shift in how effective your salespeople are.

OK. Good. I think the rest are fairly straightforward. And we have sales force wage and total fraction of the revenue.

AUDIENCE: So it seems basically everyone else made the same kind of idea in terms of the sales force, that you have some budget coming from the current money you're making. But then you would adjust your sales force with the delay.

And I just felt kind of weird about making that simplification because it's possible that suddenly revenue drops, but your sales force doesn't immediately change because there's a delay. And so there's a little time period in which you're paying your sales force with money you don't have.

And I guess you could borrow, right? But then that has other financial implications with interest rates and blah, blah, blah. So I don't know. It's just the sort of thing where [INAUDIBLE]

HAZHIR That's fair. So basically, the assumption there is that you're borrowing to pay your sales force. And if you're doing
RAHMANDAD: your cost-benefit correctly, that borrowing will show up in negative cash flow and reduction of your cumulative profit or whatever you call that.

So it's not wrong. It works fine. If you want to capture that more explicitly, you would have a stock of cash or something that is accounting for money in your bank account that you can pay.

And if you don't have money to pay, you're not paying your sales force. That basically should automatically get them out. Or maybe if they are US government, federal employees, maybe they stick around and try to work without out or something.

So we had this executive student who was telling us this story about payment system in Canada, that they had the project. And this was a project that was to be, I don't know, three years, \$300 million. And now they are-- for re-vitalizing their payment system for the Canadian federal employees.

Everybody who gets paid basically goes through the system. And then she said, now we are 10 years later and \$3 billion of cost, and this project is not yet finished. And not only that, it has been operational. So they have been paying, but they have been paying wrong salaries and not paying some people.

And it's not like just 1,000 people were affected. 50-60% of people were getting wrong salaries for months and not getting salaries for a few more months. It's like-- anyway, it was a really terrible story, but a good anecdote for project dynamics class. So that was just a digression.

OK. So I think this is-- yeah, we covered much here. Other volunteers? Actually, one question-- yeah, let's do yours. And then we can--

AUDIENCE: [INAUDIBLE]

HAZHIR That's OK. That's OK.

RAHMANDAD:

AUDIENCE: And I think based on what you said so far, I think [INAUDIBLE] correctly, so.

HAZHIR That's all fine. OK. So let's take a look here. So actually, let's go with the factories. So factory depreciating-- we

RAHMANDAD: talked about it, not important. First order draining here-- we talked about that.

Construction time, first order-- that's fine. But keep that in mind. And then you have target delivery delay versus actual delivery delay with capacity expansion rate-- so this formulation has the problem that we just discussed about [? Auriana's ?] model.

OK. So this is very kind of discrete way of thinking about it. So you're saying, if you're above, let's expand. If you're below, let's just stop expanding. So that's kind of too discrete for our typical formulation.

So you want to look at maybe the ratio of actual delivery delay to target delivery delay and use that as the pressure. The second thing is that it has the problem that it is not anchored to any of the kind of scale of your operations-- how many factories, what capacity you currently have. So that was kind of very similar to [? Auriana's ?] challenge.

So these are the two main issues here. Then we have the delivery delay. That is current. That's standard. Your production capacity is impacting delivery.

But this is another issue that you have. The minimum of backlog divided by target delivery-- OK. So you have the maximum delivery rate taken care of within the formulation, which is OK. It's a little bit kind of cleaner to take out the maximum delivery rate as the ratio of backlog divided by target delivery delay. But that's OK.

And the target delivery delay here being the driver makes things a little bit more problematic. So right now, this delivery rate will never be below backlog-- well, not never-- will not be above backlog divided by target delivery rate, delivery delay. And therefore, the delivery delay, the actual, will not go below target delivery delay under any case. Does that make sense?

AUDIENCE: [INAUDIBLE]

HAZHIR

So that because you're using the target delivery delay in the role of what we typically call minimum delivery delay, delivery rate will always be small enough that you cannot have a situation where actual delivery delay goes below target delivery delay. OK?

RAHMANDAD:

And if it never goes below target delivery delay, this [if and else] thingy-- so if actual delivery rate is bigger than target delivery delay-- so there are situations where the two will be equal. And therefore, this thing will go 0. But most of the time, this capacity expansion rate will be active. So it's not exactly what you want it to do, I think.

OK. Then we have the product lifetime. People become potential. Once they became potential, they are now pitched to pitching capacity is from sales force and limited by a minimum pitch time-- so pitch time horizon. Yeah. So this is a very similar formulation as we had with other folks.

It works with similar limitations. But the assumption that you have, which is different here, is that once you have been sold, the next time you come, again it takes the same amount of time to be sold to. And that's also OK. But we haven't yet seen any formulation that has kind of a balance between the two or allows different productivities for those different two purposes.

And then you have the effect of delivery delay on conversion. Again, there is kind of the delay here for perception of the delivery delay. That is important, I think.

Then attrition of sales force is fine, but you want to have replacement of sales force in the hiring process so that you have desired sales force minus sales force for the adjustment of sales force plus the attrition rate as the total adjustment of the-- or hiring rate.

So one thing I kind of see here in multiple places is that you kind of combine multiple things inside the formulation. So you have fraction of revenue to sales force multiplied by revenue divided by cost per salesperson. All of this is your desired sales force. OK?

So rather than this being the flow, it should be the desired sales force. And then you look at the current sales force compared to the desired sales force divided by some time to adjust-- close the gap for adjusting. So this one wouldn't actually do the job that you want. In fact, it may have even unit problems unless you have changed some of the units to be--

AUDIENCE:

[INAUDIBLE]

HAZHIR

Ah, this should be dollar per salesperson per month. That's why you don't get unit problem. So cost per sales

RAHMANDAD:

force is not dollar per salesperson. This is not a slavery. You just are paying the monthly fees. So the units are not balancing here. All right.

What else? Good. I think kind of you get the basic ideas. Question-- anybody has tried to make the formulation for fraction of budget going to sales force dynamic, depending on the size of the operations or kind of the effectiveness of the sales force? OK.

OK. If nobody has done, that's OK. So the idea there-- I mean, we don't have an example to go through it in detail. But the idea there is that, right now, you have a fraction of budget that is going to sales force. And that as a heuristic may be fine. But during different stages of operation, that fraction should change.

In practice, early on, you may actually put a lot more emphasis on the sales force. Later on, as you have a lot of customers who already know you and therefore the cost for converting them is lower, or because you just have captured all of the market and it's only the replacement rate that needs people, you want to reduce that budget for the sales force. You don't need to keep that big sales force, pay them.

And that is right now not captured here in any of the models. So how would you think about capturing that? So what would be high-level, conceptual way of capturing that?

AUDIENCE: [INAUDIBLE] base fraction of revenue that is allocated to the sales project. So if the effectiveness of the sales is at the maximum level, meaning that each sales person, for example, can recruit or teach 10 people, there would be no changes in that base fraction. But as soon as the fraction drops because the market is getting saturated, that sales budget can also drop [INAUDIBLE]

HAZHIR So basically calculate the net productivity of sales force and then use that net productivity to adjust. If that net
RAHMANDAD: productivity goes down, bring down that fraction. So that's a good first step. Anybody wants to improve upon that? Alexander.

AUDIENCE: Just a very minor thing, but you could convert the productivity into the marginal revenue of each salesperson, right? So you just multiply how many customers each salesperson is getting times the order quantity and price. Right?

And then that way you can compare that to the wage of the salesperson. So that way, if it's above 1, then salespeople are net profitable. You want to hire more of them. If it's less than 1, then you want to decrease [INAUDIBLE].

HAZHIR OK. Very good. So that's kind of a very clean, economically logical way of doing it. Basically, what is the marginal
RAHMANDAD: profits from each salesperson now? For each sales that they do, there is a marginal profit that is generated.

So is it worth having more of these salespeople or not? That's the question. And in fact, if you do it that way, you can basically make the sales force exposed to a pressure. And that pressure comes from this factor. If it is above 1, you expand. If it is below 1, you shrink.

And that 1 is the ratio of the marginal profit per salesperson divided by the salary of the salesperson. So that becomes a pretty nice endogenous way of managing the size of the sales force so that it is consistent with your profitability from those people.

AUDIENCE: And the sales force productivity would have to come from some relationship between the stock of potential customers and your [INAUDIBLE]

HAZHIR So the sales force productivity-- you don't need to worry about doing all of those calculations separately. You
RAHMANDAD: have a total sales that is happening. And you have total sales force you have. So you can get the average sales force productivity right away.

Now, that is average. It is not marginal. So this is actually one level more complex, if you want to think about it this way. So calculating the average is very easy. You already have all of the information. You just divide the total sales to the total-- but this is not exactly the marginal productivity.

Marginal productivity is, for each extra sales force, what will happen? And doing that requires actually a little bit more tracking. And the way you do it, it's not very standard. We don't have the infrastructure built into this structure right now.

So you could do it analytically. That is, basically, if you have simpler formulations, you can calculate the marginal value analytically as a separate path that is saying, OK, if my formulation for sales force impact on sales is like this, what is the marginal productivity of the sales force, which is the derivative of profitability with respect to sales force? You can write that, and calculate that, and track that.

So that would be one way to do it. For more complex models, it's even harder. But one way to do it is to actually always use a-- so this is starting to become more complex. So you add a subscript to track the value of sales if you had one more person, one more salesperson.

So you're calculating the current sales force and what is the impact on the sales. There is one pathway. And then you would add a subscript along this pathway for extras or marginally more sales force and calculate the sales under that alternative formulation. And then you look at that delta and divide it by 1, which is in this case the total difference between the two.

So I haven't seen many people use it, but that's how you would do it if the formulations are too hard to do analytical tracking of the marginal. Is the difference between marginal and average clear? Because that's the first starting point.

So marginal productivity of a salesperson is, if I add one more salesperson, how many dollars would they make? Average productivity is saying, I have 100 salespeople and I'm making \$1 million, so that's \$10,000 per person on average.

The question of, do I add one more person or do I reduce one more person, should be determined by the marginal, not the average. Average is not always but most of the time overestimating the benefit of the salespeople. And therefore, expanding or shrinking based on average will give you the wrong answer.

That is, if you increase your sales force until you have the average be 0, then you already have a very bloated sales force. Many of those people you shouldn't have hired in the first place. So that is why using the marginal is important.

Good. So I think that was kind of a conversation that wasn't obvious without having it, but I think-- OK. We could look at one more model. Anybody wants their model to be looked at?

AUDIENCE: I just have a question about what we just said.

HAZHIR Sure. Go ahead, Jake.

RAHMANDAD:

AUDIENCE: So if we're looking at a marginal profit of another sales person, when you get into actually making that, would you also have to consider the fact that if you add too many too quickly, [INAUDIBLE] might go down because your reputation goes down because you haven't built that factory yet. And you've introduced a delay. Like, do you need to get that granular with it? Or are you thinking long run [INAUDIBLE] gets to equilibrium state with a new salesperson?

HAZHIR

Yeah. So in the first cut at it, I would just do this. That is, I would say, OK, sales force is creating pitching

RAHMANDAD:

capacity. So I'll make the pitching capacity in this model subscripted with two versions. One is with the current sales force, another with sales force plus one person.

And then wherever it goes-- so it is changing the customer conversion. I'll have two versions of customer conversion. One of them is operating on the stocks. The other version I'm just-- for keeping track of how things are happening. And then that customer conversion somewhere shows up in my profits. Yeah. In the accounting profits, I'm also tracking that sales force and so on.

So that version is fairly short term-focused. It is not really capturing the longer-term consequences of bringing this new salesperson. Doing those longer-term consequences is much harder. It is actually more precise. That is a good calculation of what the right balance is, should account for second and third order effects that would require adjustments of other stocks.

But then you basically would be needing to-- for every time step, you need to simulate the model with that alternative formulation or that alternative number of sales force, do a calculation of the marginal, then come back and decide how many people you want to have.

So in a way, it is what organizations are doing. Organizations have their simulation models or their spreadsheet models that try to forecast what would be the impact of each additional sales force over the time and therefore bring it back into that decision every period of time.

Now, they don't do it every time step in the simulation sense. They would do this maybe periodically, every quarter or something. So conceptually, that is not too far from what the organizations also do, but doing it in these models becomes exceedingly hard.

So that would require a separate simulation of some simpler version of the model-- not all of the model necessarily, but some simpler version of the model every time period to inform just one of the decisions in the model. And that is logistically hard to do.

In Vensim, you basically need to define some kind of external function that goes and calculates that, maybe calling Vensim separately, doing that simulation, then coming back, and plugging in that number into the next time step. And it's just a headache I'm not going to worry too much about. But sometimes it becomes important and you need to do it. So in those cases, yes, think about it.

So Aria-- for her general exam, one part of the question was about the marginal value of investing in new shows for streaming services. And these investments have long term impacts. Because it is not just, next period, how many I sell. But it is over the life of this show how many would I sell, and how many it kind of reduces the value for my other shows-- it cannibalizes my other shows-- and then how many new customers it brings to me.

So it was a very complex decision. So coming up with a marginal value was a very non-trivial task. And ultimately, it was kind of, how can you approximate that using relatively simple, manageable analytical formulations? Anyway, that's kind of a long answer to a question that is not easy, ultimately.

OK. But now probably it's a good time to just review the problem for next week, given the limited time we have. So next week, we are having the endogenous diffusion model. So this is kind of motivated by Jack Homer's research on pacemakers.

So this he did for his thesis. So this is an old, old piece of work. But he continued working on this space. It's a very generic way of thinking about diffusion.

So typically in diffusion models, we think about a single concrete product and how it gets adopted. But if you think about a product that is evolving over time-- it is getting better, features and functionalities are added to it.

So pacemakers are a good example. Because when they were introduced-- I don't know, in the 1970s or early '80s-- no, '70s, I think. They were very big, bulky, only useful for the most critical patients who would die without them or something like that. It was a very invasive surgery.

But over time, they became more efficient, smaller. Their signaling became more sophisticated. Their battery life extended. All of those increased the use cases that pacemakers could be used for so that these days many people who otherwise can survive very well and have a decently normal life would still benefit from pacemaker. Because on the margin, it adds value for them as well. So that is expanding the size of the market.

Now there are additional things that come into play-- that you add these new features and functionalities. You make the product potentially more applicable to a larger customer set, but you're also introducing bugs. You're introducing problems that are not known at the beginning.

So discovery of those problems, fixing of those problems, and the reputational impact that those problems have on the product are also important in the adoption. So it can even create oscillatory modes.

So he showed that, for example, typically in the case of pacemakers, there is delays in research that identifies and captures those side effects and problems. And that delay leads to some oscillatory mode in adoption of pacemakers-- that kind of they come out with new versions. They create lots of excitement.

But then early research typically kind shows some disappointing results that then needs to be fixed, those problems. And that brings down adoption for a while. And then it starts to recover.

So that's what your task is to formulate, a model of adoption that is not your typical Bass diffusion model. In fact, the way Jack formulated it-- and I suggested that you can formulate it with that idea-- doesn't use the Bass infrastructure at all.

It kind of says there is a indicated level of potential users. And the actual users move towards that indicated level. But the speed by which they move towards that indicated level, the time constant there, could be a function of how many other adopters are out there.

So this is a different way of capturing the Bass diffusion model's reinforcing loop. So the Bass diffusion model says people who adopt it talk with people who don't have it. And that leads to adoption.

This alternative says there is an indicated level of how many ultimately would adopt. There is a current level. And you look at the gap. You close that gap over a time constant. But that time constant can become smaller if you have a lot of people who already have adopted because then the information spreads faster.

So that's a different version of a Bass core idea which accounts for the advertisement channel or the alternative channels as well. Because the time constant is never infinite. So there is a max time constant. If nobody else's have it, there is still a fractional rate of movement towards this level.

So that's a kind of an alternative way. So think about it. Use it just to see how it works.

So you'll see the problem definition in the folder. It is a little bit less well defined. So you will need to make more architectural choices. I think this week, the problem-- even though it was a broader model boundary compared to the previous weeks, it was fairly well defined.

So we see a lot of similarity across different submissions. And overall, you folks had done well. I think many of the submissions were in the right space. Now, we could improve and change some of these things.

So this one might be a little bit more challenging. That's why I put it a week later. But it shouldn't be too hard.

OK. So that's the plan for next week. Any questions on this exercise?

AUDIENCE: So there is a bit of word of mouth here, right?

HAZHIR Yes, there is a bit of word of mouth.

RAHMANDAD:

AUDIENCE: Both positive and negative-- more doctors tell people about the increased scope but also the bugs as a result of the newly [INAUDIBLE].

HAZHIR Yeah. So how you deal with that is kind of a little bit of an open question. So I left it there at this level, that bugs

RAHMANDAD: are there. And they get discovered and fixed. But when they get discovered, they reduce utility. In fact, some of the bugs, they don't need to be discovered broadly and perceived broadly.

Just the fact that it is there, you as a user will feel it. It does have an impact on your utility. But the people who have not adopted it usually need to hear about it. So that discovery process is important.

OK. So that's for the next week. Do please also revisit your proposals. Let's kind of finalize those so that next week everybody has a version that is kind of close to final that others-- when they go through the exercise we talked about for the week of 18, they can look at those problem definitions.

Cool. Any questions? OK. So enjoy your weekend, folks. Good to see those online. And see you next week. Yeah.