Thought Paper

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A Pragmatic Approach to Probabilistic Planning

Embracing Supply Chain Uncertainty

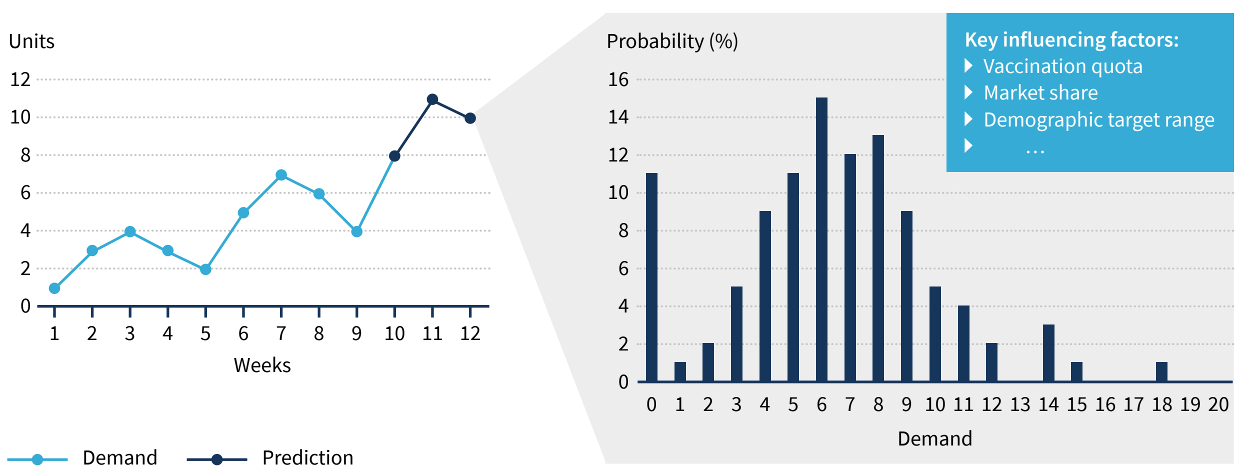
In the dynamic landscape of modern supply chains, where disruptions and uncertainties have become the norm rather than the exception, traditional approaches to supply chain planning often fall short in providing reliable and risk-aware strategies. One of the most promising advancements in this field is probabilistic supply chain planning, a paradigm that embraces uncertainty by offering insights into multiple possible future scenarios and their associated probabilities. This thought paper delves into the intricacies of probabilistic supply chain planning, exploring its advantages, methodologies, implementation challenges, and its potential to reshape the way future supply chains are managed. A pragmatic approach to probabilistic planning will be illustrated by an example from the vaccination industry.

Probabilistic Demand Planning

Supply chain planning starts with gathering demand signals to get an understanding of the market size and development with the target to derive when and how much of a product needs to be made available. Traditionally, supply chain planning has heavily relied on so-called point forecasts, aiming to predict future demand with a single value per prediction. While this approach is intuitively easy to understand, it tends to overlook the inherent uncertainty and variability present in real-world demand patterns.

Probabilistic forecasting shifts the focus from point estimates to the probabilities of various future scenarios. Instead of presenting a singular prediction, probabilistic forecasting provides a range of possible outcomes along with their associated probabilities, empowering decision-makers to comprehend and address the inherent risks more effectively. Traditional deterministic approaches struggle to consider multiple scenarios, often leading to suboptimal decisions when unexpected events occur. Probabilistic forecasts encompass a wide range of scenarios and include low-probability and “zero demand” scenarios, i.e., scenarios that would lead to a demand of zero such as obsolescence of the product. Therefore, they provide a more comprehensive view of the future landscape and tend to outperform traditional point forecasts, especially in volatile environments.

Figure 1: Traditional point forecasts vs. probabilistic forecasts



Transitioning from traditional point forecasts to probabilistic forecasting requires a structured implementation process. There are two approaches: a sophisticated and rather theoretical textbook approach, and a non-exhaustive but pragmatic approach, on which we will focus in this thought paper.

Approach 1: The textbook approach to probabilistic demand planning

The most advanced way to calculate probabilistic forecasts is to make use of simulation models that can capture multiple planning parameters and data sources to derive demand probability functions. While generating holistic and continuous probability functions, this approach requires ERP systems that can operate with probability functions, which is not the case for most available systems yet. It also demands extensive organizational and process maturity as well as highly skilled planners and analysts. The approach consists of the following steps:

- **Model selection**
  The first step involves choosing appropriate probabilistic forecasting models that align with the characteristics of the demand data. Bayesian models, Monte Carlo simulations, and other statistical techniques can be employed. Validation using historical data ensures the accuracy and reliability of the selected models.
- **Parameter definition**
  Uncertainty arises from various sources, such as supply chain disruptions, market developments, and external factors. Probabilistic scenarios must capture these uncertainties by considering different combinations of possible events. This stage defines the confidence levels and parameters required to derive future scenarios.
- **Data sourcing and connection**
  Identifying relevant data sources and validating master data quality is essential. Establishing a standard operating procedure (SOP) for updating data ensures that the probabilistic forecasts remain current and accurate.
- **Model application**
  Probabilistic models need to be fed with scenarios and relevant data. Depending on the model selected above, simulations may be conducted to refine demand probability functions. This step ensures that the models accurately represent the uncertainties inherent in the supply chain.
- **Application of the probabilistic demand plan – pilot end-to-end planning**
  The heart of probabilistic supply chain planning involves determining optimal supply quantities based on probabilistic demand forecasts. This helps prevent shortages or overproduction. Additionally, developing contingency plans and strategies to mitigate the impact of unexpected events enhances the overall resilience of the supply chain. This can be best tested for a selected range of products, before scaling the process up to the entire portfolio. Thus, the new process can be trained in detail and continuously improved. The next chapter explains how to derive optimal supply plans based on a probabilistic forecast.

Approach 2: A pragmatic probabilistic demand planning approach

A pragmatic way to incorporate probabilities of different scenarios into the demand planning process is – instead of deriving highly complex and continuous probability functions – to focus on key influencing factors for demand, and to derive a limited number of scenarios with corresponding probabilities.

- **Detect key influencing factors**
  The first step of a pragmatic probabilistic demand planning process is to define key influencing factors for demand. In our example of the vaccination industry, those factors could be market share, vaccination quotas, and the size of the demographic target group. It is important here that the selected drivers are independent of each other and can be expressed as a percentage of the total market size.
- **Derive outcomes for influencing factors**
  After defining key influencing factors for demand, the commercial/sales department is required to define multiple possible outcomes for the development of each selected factor. For each of the defined outcomes, a possibility to occur needs to be estimated. For example, a vaccination quota of 70% will be reached with a possibility of 10%.
  It is important to note that for each influence factor, all attributes together must have a probability of 100%.
- **Define scenarios**
  From the various individual outcomes and associated probabilities, scenarios can be modeled easily by weighting the total market size by different combinations of influencing factor outcomes. With that, each scenario is automatically associated with the probability to occur. This is shown exemplarily in figure 2 for the maximum demand scenario.

Figure 2:
Exemplary scenario modeling

SCENARIO	MAXIMUM DEMAND
Total market size	80 Mio.
Market share (probability)	60% (20%)
Vaccination quota (probability)	80% (40%)
Demographic target range (probability)	90% (25%)
Demand outcome	80 Mio. x 60% x 80% x 90% = 35 Mio. doses
Outcome/scenario probability	20% x 40% x 25% = 2%

The number of possible scenarios is determined by the number of defined influencing factors by the power of the number of defined outcomes per influencing factor. For three key influencing factors and three possible outcomes, we will get a total number of 27 scenarios. As this is a high number of scenarios to be handled, scenarios can be aggregated by e.g., regarding the mean of the outcome of several scenarios and assigning it the sum of probabilities of the chosen "bundled" scenarios.

To incorporate probabilistic demand plans into the end-to-end supply chain process, the derived scenarios and probabilities need to be translated into optimal supply plans. How this can be done in a pragmatic way and without systems that need to be capable of handling continuous probability functions will be explained in the following chapter, in which only five aggregated scenarios are derived from the 27 scenarios above.

Probabilistic Supply Planning

Like probabilistic demand planning, probabilistic supply planning is a forward-looking approach that recognizes and exploits the inherent uncertainty in supply chains. It acknowledges that factors like demand variability, lead time fluctuations, and external disruptions can significantly impact a company's ability to meet its supply commitments. At its core, probabilistic supply planning uses scenarios associated with probabilities that result from probabilistic demand plans to account for uncertainty in various supply chain parameters. By doing so, it provides decision-makers with a more realistic and actionable view of potential outcomes and risks, enabling them to make informed decisions that maximize the overall supply chain performance.

A pragmatic approach to probabilistic supply planning

A simple example of how a probabilistic supply plan can be derived from the probabilistic demand plan is shown in the following figure:

Figure 3:
Pragmatic probabilistic supply planning

	Price 100 $	Cost 10 $	PLANNED SUPPLY QUANTITY (Mio. doses)				
SCENARIO	PROBABILITY	DEMAND (Mio. doses)	35	30	11	5	2
Maximum	5%	35	$ 3.150 Mio.	$ 2.700 Mio.	$ 990 Mio.	$ 450 Mio.	$ 180 Mio.
High	10%	30	$ 2.650 Mio.	$ 2.700 Mio.	$ 990 Mio.	$ 450 Mio.	$ 180 Mio.
Medium	35%	11	$ 950 Mio.	$ 1.000 Mio.	$ 990 Mio.	$ 450 Mio.	$ 180 Mio.
Low	20%	5	$ 150 Mio.	$ 200 Mio.	$ 390 Mio.	$ 450 Mio.	$ 180 Mio.
Minimum	30%	2	$ -150 Mio.	$ -100 Mio.	$ 90 Mio.	$ 150 Mio.	$ 180 Mio.
EXPECTED PROFIT (Mio. $)			$ 740 Mio.	$ 765 Mio.	$ 600 Mio.	$ 360 Mio.	$ 180 Mio.

Profit-optimal unconstrained supply quantity ($ 765 Mio.)

- Demand with probabilistic forecast and different scenarios
- Point forecast (expected demand) of 11 Mio. doses does not lead to profit-maximizing supply plan (~ $600 Mio. expected profit)
- With probabilistic forecast, an optimal supply quantity of 30 Mio. doses is estimated (~ $765 Mio. expected profit)
- Expected profit increase through probabilistic supply planning: $165 Mio. (27%)

From the probabilistic demand plan, various demand scenarios, their probability of occurrence, and their impact are already known. In a deterministic view, one would only regard the demand outcome with the highest probability or a weighted average of multiple outcomes. In this example, the expected demand would be 11 Mio. doses of a vaccine (see third row in Figure 3). A deterministic supply plan would use that expected demand to calculate a planned supply quantity. The final supply quantity is of course based on additional parameters and depends on the respective replenishment strategy but would be somewhere in the area close to 11 Mio doses.

A probabilistic supply plan considers all possible scenarios and compares those to multiple feasible choices of supply quantities. An expected profit can be calculated for each combination of demand and supply outcomes. Weighted with the probability of each scenario, the analysis leads to an expected profit for each choice of supply quantities. In a profit-maximizing model, one would then choose the supply quantity with the highest expected profit. In our example, the profit-maximizing supply quantity is 30 Mio. doses with an expected profit of $765 Mio. The deterministic supply plan with a supply quantity of 11 Mio. doses would only lead to a profit of $600 Mio.

In practice, multiple planning runs would be required to calculate probabilistic scenarios. A pragmatic approach could be to start with a rather low number of possible scenarios and increase the number of scenarios gradually with increasing process maturity.

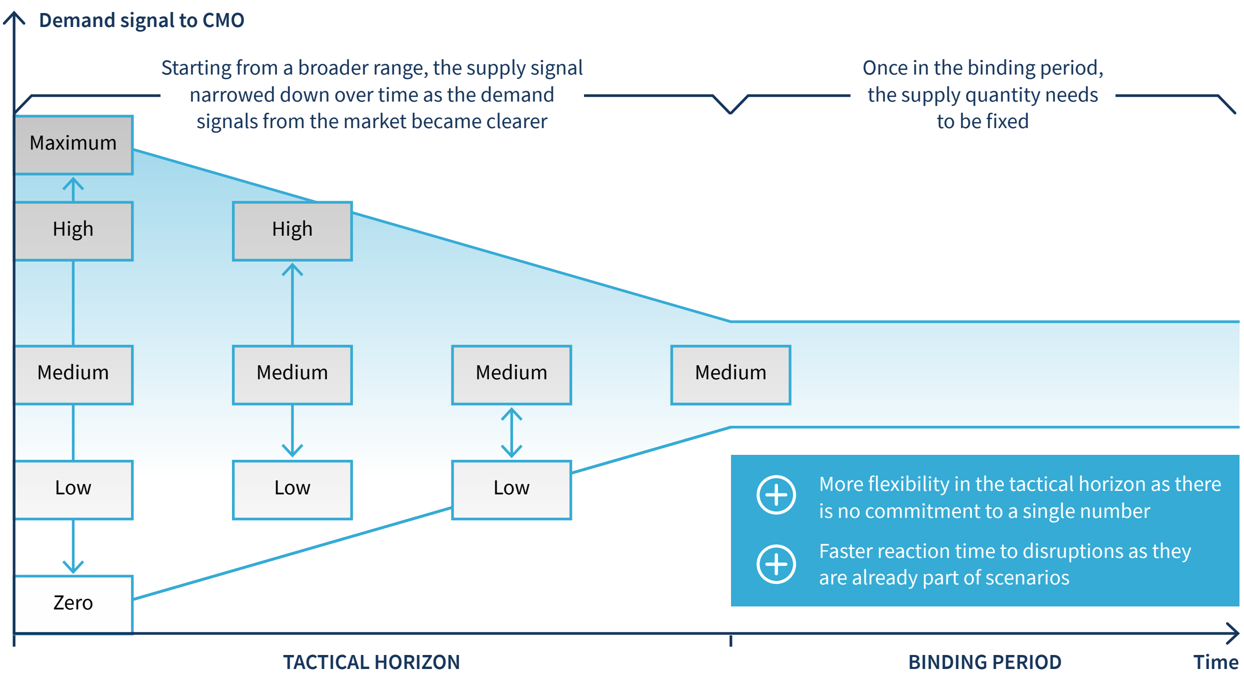
Once local profit-optimal delivery plans have been calculated, they must be aligned with global priorities such as strategic customer priorities, contractual requirements, service level targets, supply and production capacity constraints, and potential penalties for failing to meet demand. This makes probabilistic demand and supply plans a key decision input for a Supply and Operations Planning (S&OP) process.

Probabilistic supply planning for capacity reservations

In our simplified example, probabilistic supply planning outperforms deterministic supply plans when it comes to profit optimization. However, there is another advantage in terms of supply capacity reservations, which is another important aspect of S&OP processes. In a deterministic model, one would need to communicate a single number to the supplier or production facility at the beginning of the tactical horizon. This number will change over time, which requires a high degree of flexibility from suppliers and production planners.

In the case of probabilistic planning, planners can communicate certain ranges of supply quantities to their suppliers or production planners, as they are aware that multiple scenarios can occur. This range provides planning flexibility for both sides. Over time, the communicated range can be narrowed, as certain events can already be observed that exclude certain scenarios. This also reduces the amount of required re-planning within the tactical horizon as multiple scenarios were already planned at the beginning.

Figure 4: Capacity reservation with probabilistic supply plans



Advantages and Challenges of Probabilistic Planning

Probabilistic planning equips decision-makers with a more comprehensive view of potential outcomes and risks. This allows for more informed decisions that consider the likelihood of various scenarios, ultimately leading to better supply chain performance. By identifying and preparing for potential disruptions, organizations become more resilient in the face of uncertainty. Probabilistic planning enables them to proactively manage risks, reducing the impact of unforeseen events. Optimizing inventory levels and lead time management based on probabilistic models can lead to additional cost savings. With a more reliable supply chain, companies can enhance customer satisfaction by consistently meeting delivery commitments, even in the presence of disruptions.

While probabilistic planning offers numerous advantages, its adoption requires a thoughtful approach. Reliable data is essential for accurate probabilistic modeling. Companies must invest in data collection, cleansing, and validation to ensure the effectiveness of their planning processes. Implementing probabilistic planning also requires a shift in skill sets within the supply chain team. Data analytics and statistical expertise become crucial for a successful implementation. In addition, investing in advanced supply chain planning software that supports probabilistic modeling is necessary. While many software vendors claim to offer advanced probabilistic forecasting engines, few offer comprehensive end-to-end planning solutions. Therefore, it is worth considering starting with a more pragmatic way to introduce probabilistic thinking into an organization, as shown in our simplified example.

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