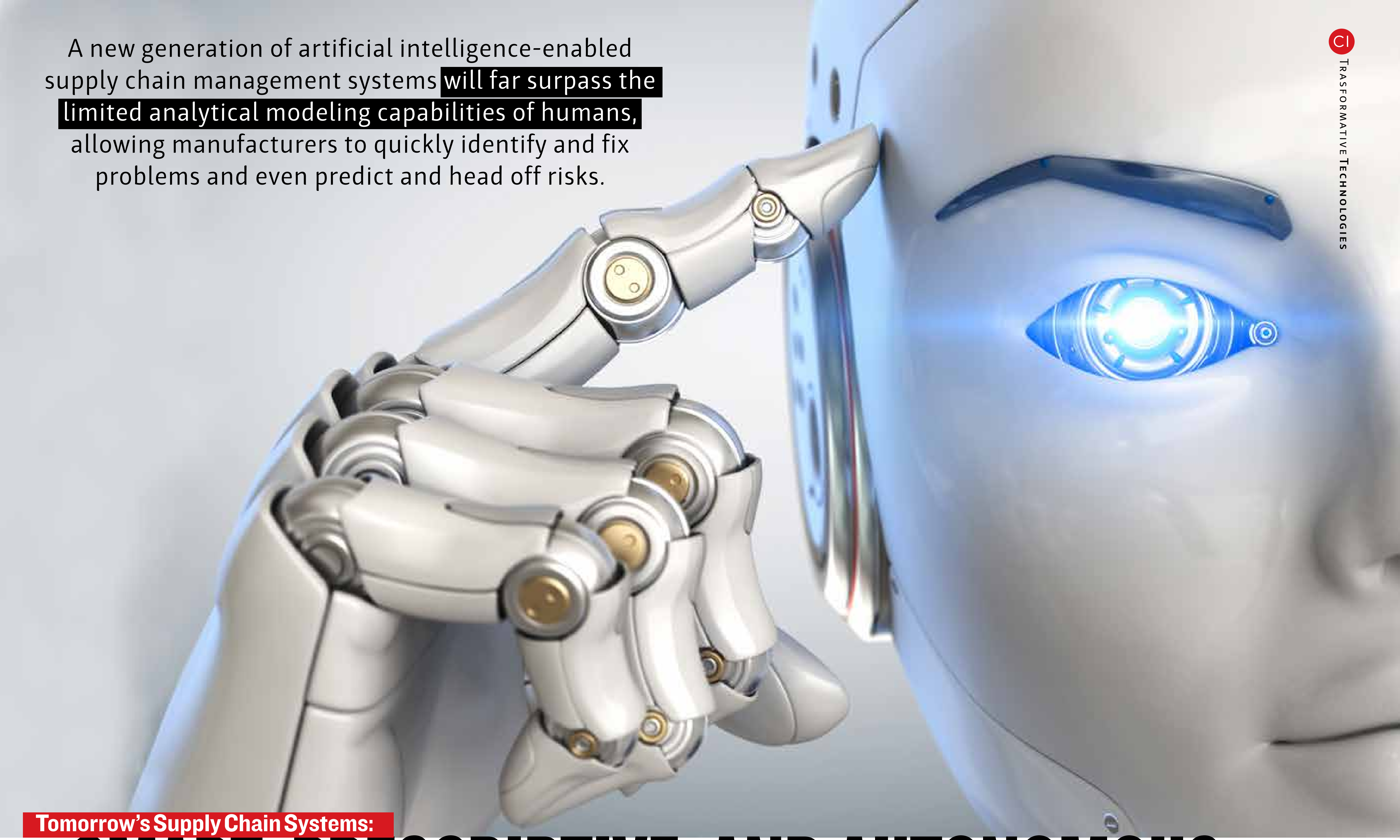
A new generation of artificial intelligence-enabled supply chain management systems will far surpass the limited analytical modeling capabilities of humans, allowing manufacturers to quickly identify and fix problems and even predict and head off risks.



## Tomorrow's Supply Chain Systems:

# SMART, PRESCRIPTIVE, AND AUTONOMOUS

By Cyrus Hadavi

AS IMPORTANT A ROLE AS IT HAS PLAYED IN INCREASING business productivity, automation is simply the repeated execution of predictable tasks. It does not improve or adapt its own performance, as humans do, when various conditions and aspects of the business change.

In much the same way, most of the supply chain planning systems now in use are programmed to respond in predictable, pre-determined ways even when conditions change and the assumptions are no longer as valid as originally assumed. As business conditions have become more volatile, this has led to planning systems that too often fail to generate the best decisions.

But the good news is that this situation is about to improve. We are now at a point where systems can be created that adapt to changes in their environment, learn from their experiences, and get smarter by themselves the more they are used. They can self-repair and self-improve as the world around them changes. They can even act much like autonomous vehicles, planning and operating the complex supply chains of companies without much human interaction.

**K. Cyrus Hadavi,** PH.D., is chief executive officer and chairman of the board of Adexa, Inc.

### *The Limited Human*

A high reliance on the users to make decisions, or guide the system, has been one of the major limitations of past supply chain planning approaches. That's because, with every iteration of planning, there are millions of variables to be considered, billions of versions of plans that can be produced, and thousands of variables which are constantly and dynamically changing. So it is impossible for users to come close to constructing optimal plans. In most cases, therefore, planners end up making "good enough" decisions without knowing what opportunities have been lost. This results in poor decisions that meet only minimal objectives of the organization.

The fact is that, even if one deployed hundreds of individuals to find the right answer, it would still lead to suboptimal results due to the distributed nature of the data and the immense magnitude of different alternatives. An example of this can be seen in asset-intensive companies such as semiconductor manufacturing or aerospace production where billions of dollars are invested in equipment that is managed by individuals using spreadsheets leading to losses of tens of millions of dollars in underutilized equipment and excess work-in-progress inventory.

Planning requires all possible constraints and, often fuzzy objectives to be taken into account. The system must search for a solution that not only meets all the objectives but also optimally satisfies all the constraints. Systems are capable of doing this in near real-time. More recently, with the use of AI search algorithms and machine learning techniques, they can improve their own performance as they operate over time. They can learn from their mistakes and use their successes to become better and better in planning as well as executing the generated plans.





So what are the trends and factors contributing to the need for a next generation of supply chain planning systems that are smart, predictive, and autonomous? Here are a few:

- Increasingly, supply chains behave like living organisms, constantly changing in character, albeit slowly. Planning systems must have the ability to measure the impact of new parameters dynamically and adjust the plans as needed;
- There are underlying trends in every supply chain that are not necessarily obvious to humans;
- Sending messages and waiting to hear from suppliers is a very slow process that cannot deal with the complexity of large supply chains in real-time. Planning systems need to predict what will be required, and when;
- Key Performance Indicators are good, but they are a measure of the past. By the time they alert you to a problem it might be too late. We need to have a measure of the future. This can be achieved by modeling the supply chain and predicting what actions are needed proactively;
- The planning system must be able to produce the plan as well as execute it. It should take the role of a self-driving vehicle that is constantly planning, adjusting, and figuring out how to get to the final destination;
- External factors such as geopolitical events, acts of God, and environmental regulations can influence supply chains. So systems need to plan to mitigate risk proactively;
- Users are now used to voice-activated appliances and apps such as Alexa and Siri and expect the same level of convenience. So, systems need to communicate in natural languages rather than forcing users to type, search, and read tables on their laptops.

### *How it Works*

There are a number of AI approaches that can be used to enable smart supply chain planning systems. Such methods have been made possible by the availability of very high speed processors and relatively inexpensive computer memory. Here are some of the capabilities that AI will enable in next-generation supply chain planning systems:

#### › Self-Correcting Models Using Data Analysis

Every model of a supply chain is built with certain underlying assumptions. Examples are supplier lead-times, equipment

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availability, and yield. Increasingly, these models will be improved with the use of large data analysis methods of learning in which the system compares the existing model assumptions against the actual events in the supply chain, looking for trends and patterns. When a significant deviation is detected in the model variables, the system performs a self-modification of the assumptions to update the model, resulting in more accurate predictions and prescriptions.

For example, if a supplier's delivery performance tends to be generally faster than the one previously assumed, then by updating the model parameters, we can enhance our responsiveness to clients. To this end, a self-correcting supply chain is constantly evaluating and justifying the accuracy of the model to ensure very high fidelity to the true current values.

*"AI-enabled supply chain systems of the future will be able to proactively examine potential future risks and recommend backup plans to avoid possible undesired outcomes."*

### › Survival of the Fittest through Machine Learning

In performing demand forecasts today, users typically try to come up with a few policies and then select the one that best fits for a given set of data. However, there may be other combinations of policy parameters that yield even better predictions. To this end, the next-generation supply chain planning system will experiment with other untested policies to find the superior ones for a given set of attributes of each data set. It will use machine learning neural network techniques to examine the "genes" of different policies to find the data attributes that are good predictors for the best policy to be used.

By mutating these genes, the system can even invent new and improved policies. It can do this for every planning cycle period and keep trying to find stronger policies that will survive and grow while eliminating weaker ones for a given set of data attributes. Given the extremely large number of possible combinations of different policies, humans are typically able to consider only a handful of them. Systems, however, can examine millions of different combinations to find the best fit to predict future sales.

In the same manner, next-generation systems will monitor and evaluate user inputs and their changes to the forecast. Over time, characteristics of individuals' inputs can be predicted. System will recognize how optimistic or pessimistic each individual's forecast might be and make proper corrections by adjusting the weightings on their inputs.

### › Algorithmic Inventory Planning

In a typical supply chain, the biggest mystery has been how much inventory to keep and where to keep it. In raw material, intermediate buffers, storage locations, finished goods, or in distribution centers? Keeping inventory in the later stages of the supply chain is more expensive but makes your company more responsive. However, keeping more inventory in the early stages of the supply chain is less costly but increases the lead-time to delivery.

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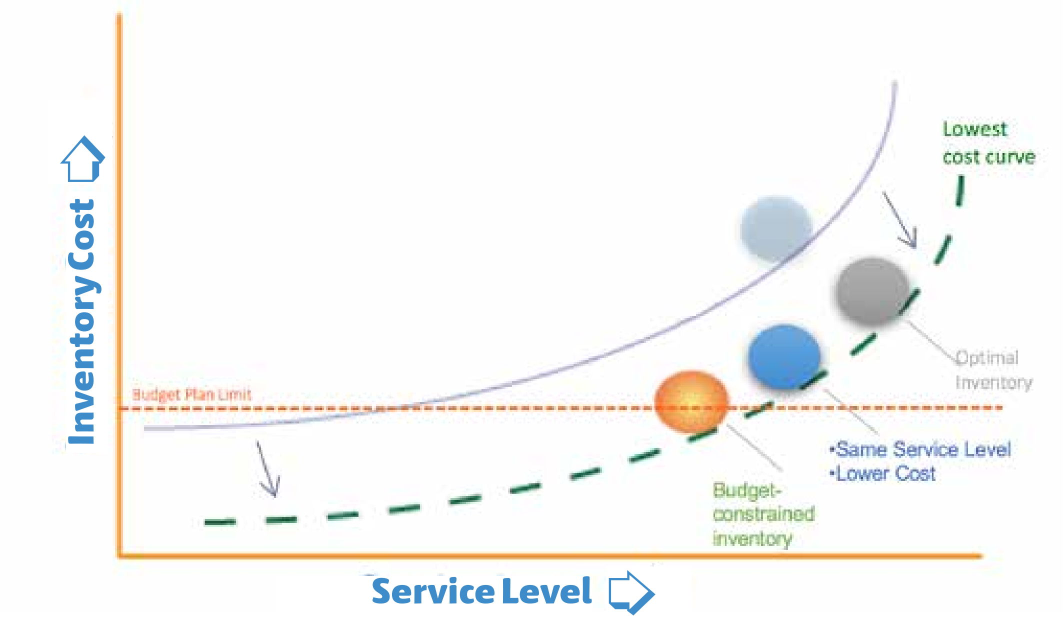


Fortunately, there are algorithms such as Gradient Descent that can be used to optimize how much of each part should be available and where in order to balance the objectives of cost and responsiveness. This technique, also referred to as Multi Echelon Inventory Optimization (MEIO), is an example of a prescriptive approach to improving supply chain operations.

While the MEIO concept has been around for a while, algorithms used now are far superior to the ones used 10 years ago in that they take into account multiple layers of the supply chain at the same time, not just one level at a time. Modern MEIO algorithms can yield prescriptive results in minutes rather than taking days to solve for millions of variables in a typical inventory optimization problem.

The inventory optimization problems that these algorithms can effectively solve are illustrated in Figure 1. The dotted line prescribes much better operating locus for any given service level and/or cost. The system is constantly working in the background to figure out the best possible curve to operate on, based on users' objectives of cost and delivery performance.

Figure 1- Best operating locus to get the lowest cost (inventory kept) for a desired service level

### › Learn from the Experts

Most planners have a bag of tools that are used to address exceptions and issues at hand. For example, when there is shortage of a material, causing late delivery of an order, they might authorize use of more expensive substitute material, preempt an order in favor of a late one, or simply call the supplier to expedite delivery. By observing every time an issue arises and an action is taken by the expert, the AI-enabled system can remember and determine if there are patterns that indicate useful solutions that can be deployed in future instances. An example of a possible pattern is that the planner uses the substitute material only for high priority orders. Or when the order is more than 10 days late, or both.

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### Mitigate Future Risks

The above predictive and prescriptive techniques are all based on evaluations of how historical data has behaved. However, given that supply chain systems model the supply chain, it is possible that this model can be used to predict future patterns of behavior and future risks. By running the model multiple times (as frequently as needed) over time, interesting and useful patterns can emerge regarding how the state of the supply chain is expected to change. For example, perhaps too much use of a substitute material (at a higher price) to ensure on-time delivery is expected to occur during the summer season. This is an indication that supplier lead-times for the original material may be too long or incorrect; it may be that the actual minimum (safety) inventory is too low during summer, or it might imply that the demand for a certain product is trending much higher than before.

AI-enabled supply chain systems of the future will have the capability to come up with such hypotheses and then test them against the available information to find out the underlying causes of higher cost or poor delivery performance affecting certain customers or products. There are obviously many other risks that the systems will be able to monitor, including single-sourced materials, suppliers in earthquake zones, and shortages of capacity.

The main point in this approach is that the system picks up patterns and trends that are not necessarily visible to the user who may be focused on just one instance of an event rather than trends that stretch over future months or even years. Immediate problems can easily be corrected by the user but the trend is much harder to detect. AI-enabled supply chain systems of the future will be able to proactively examine potential future risks and recommend backup plans to avoid possible undesired outcomes.

Today we are capable of building supply chain systems that can take the role of an apprentice that keeps learning and improving with experience. Within the next decade or so, we foresee the possibility that we will be able to plant a novice-level system into any existing supply chain environment and, over time, just like a seed, it will keep growing to become an intelligent optimizing machine, an expert, tailor-made expressly for that specific supply chain. It will be able to keep up with all the on-going changes and get more robust with time.

As these smarter, prescriptive, and autonomous supply chain systems of the future emerge, the challenges that we should expect are inevitably the cultural ones involving the extent to which we can trust the systems to run the multibillion dollar supply chains. Much like the situation with today's autonomous vehicles, there will be doubts, skepticism, and exceptions. But, none will stop the foreseeable power and speed of such systems to improve over the limited analytical capabilities of humans.

Where does this leave us as humans? Well, it is safe to assume that we will remain still in charge, and we will still be in a position to use our creativity to make strategic decisions of much higher value. In that regard, machines have not yet caught up with humans. Perhaps they will at a not so distant time in future. M