The Rise of Computer-Enabled Supply Chain Design

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Engineers across all practices, industries, and applications are dealing with the increasing complexity of systems, pushing the limits of engineering and our ability to grasp the large and complex. Whether it's designing an iPhone, a semi-autonomous rover to land on Mars, or a modern, fast and efficient supply chain, an increasing level of sophistication is required. In Supply Chain Design, this growth is being driven by increasing business complexity, access to "big data," and Moore's Law.

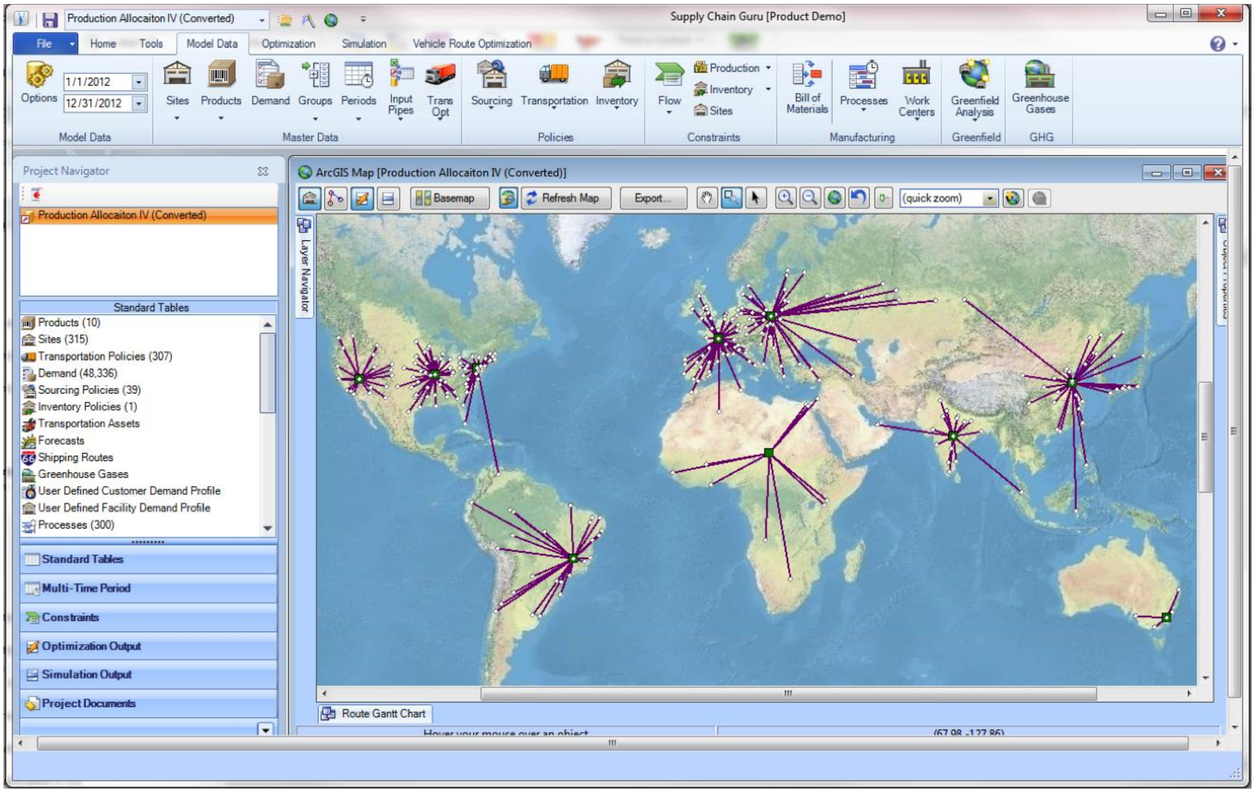
What is Supply Chain Design?

Like all fields of design, engineers in Supply Chain Design sift through a vast quantity of options to arrive at the best design – one that meets the needs of the business and its customers with minimum cost, risk, and environmental impact. Decisions about where to manufacture and stock products, which transportation modes to use, and what service levels to provide can either give a company a competitive advantage or leave it vulnerable to competitors and service disruptions.

Today's supply chain designers increasingly use large-scale mathematical programming models (with the help of optimization- and simulation-based software tools) to evaluate trade-offs between cost and performance. These tools enable the sophisticated modeling of end-to-end supply chains to evaluate a large number of alternatives, suggest new configurations, and test the robustness of the alternatives before proceeding with a costly implementation.

Supply Chain Design has become a respected area of Industrial Engineering, with dedicated academics, practitioners, software vendors, and consultants. Over the last twenty years, the field has transformed from spreadsheets and a few early heuristic-based tools to modern tools and techniques which have become the standard for supporting critical design decisions in leading companies.

Figure 1: Modern Supply Chain Design Software



A screen image of a modern supply chain design software depicting a global distribution network.

The Rise of Optimization and Supply Chain Design

Mathematical historians credit Leonid Kantorovich, a Soviet economist, with developing linear programming (LP) in 1939, applying it first to the lumber industry and soon thereafter to the war effort. In 1947, an American, George Danzig, published the Simplex method for solving LP problems, leading to broader applications of the approach.

In Supply Chain Design, the first LP models were used to answer network flow questions, like the amount of volume for each node (*i.e.* facility) or arc (*i.e.* transportation lane) in a given network configuration. These analyses became commonplace in the 1980s and early 90s, being used, for the most part, to identify the best locations for distribution centers. At this time, it was common to refer to this type of analysis as “Network Optimization;” the term Supply Chain Design would come much later once the design capabilities became more robust.

Linear programming led to the development of mixed integer programming (MIP) which has been substantially more useful in Supply Chain Design. It allows for the direct consideration of on-off decisions and step-functions (*e.g.*, deciding if a facility or manufacturing line be *on* or *off* and how large should it be). MIP is highly effective, but it creates an enormous amount of mathematical complexity, and it can break down badly in real-world applications. Like an efficient searching algorithm, MIP looks across the millions of options and cuts off entire sections of the solution space that can be proven to be worse than the current best solution. This way, only a fraction of the network configurations actually have to be solved to determine a global optimum. But even then, MIP requires large amounts of memory and time – oftentimes more than can be solved on current hardware in a business-reasonable amount of time.

> ***MIP vs. enumeration in the Real World***
> *Mixed integer programming (MIP) involves a massive amount of mathematical complexity, but is useful in solving otherwise intractable problems. Consider a small system of three warehouses (A, B, and C) for example, where each one can be either "on" or "off." The number of alternative network configurations to evaluate is 2^3 or 8 (A, B, C, AB, AC, BC, ABC, or none of these). If there were 10 warehouses, there would be 2^{10} or 1,024 configurations. But, even then, it is still not impossible to simply test each one by running an LP 1,024 times and choosing the lowest cost (which is what mathematicians like to call "enumeration"). Now, imagine Coca-Cola's U.S. finished goods warehouse network with over 400 warehouses. The number of options, 2^{400} or around 2.6 x 10^{120}, is more than the estimated number of atoms in the universe (which is $\approx 10^{80}$ in case you're interested). Enumeration breaks down badly in real-world applications.*

Recent Advances in Supply Chain Design

Over the last decade, the increase in processor performance and the correlated drop in cost as described by Moore's Law (see Figure 1) have provided a dramatic increase in the speed, complexity and size of Supply Chain Design models. The most important advances have allowed for the consideration of additional detail and accuracy, thus increasing confidence that the model represents the actual state. Like AutoCAD, the more detailed and accurate the model, the better (to a point of diminishing returns, which is still pretty far off in Supply Chain Design). Key recent advances include:

- **Computer hardware** moving to 64-bit Windows. Under a 32-bit system, the MIP solver was limited to using 2GB of memory (up to 3GB in some configurations). The removal of this constraint, coupled with the low incremental price, has led to an explosion of model complexity in recent years. Also, the common availability of multi-core and multi-processor hardware in recent years has been a step-change in modeling capability. Solving an MIP model generates many sub-problems and is, therefore, well suited to a multi-threaded approach.

  Cloud-based solving technology is further removing barriers to large-scale modeling. Some vendors have built this capability directly into the software – where the user can opt to connect to a remote solving-focused server maintained by the software vendor to solve one or more larger problems. Services like Amazon Cloud also enable users to push the limits of high-end hardware with a fraction of the hardware investment.

- **Big data systems** make it possible to access and manipulate the large datasets which underlie Supply Chain Design models. A company's historical order history, shipment history, and production history – all at the transaction level – are the preferred inputs to the modeling process to ensure an accurate and unbiased model. The rise of business data warehouses which provide easy access to this data has increased the use of historical data for analytical purposes, in turn increasing the focus on data accuracy.

  In addition to historical data, Supply Chain Design models also require what is called "design data" – information about options that did not exist in the historical network, such as candidate transportation lanes and potential facilities. Accurate and unbiased "market data," such as freight costs, is also critical to the success and credibility of the analysis. Big data systems empower large-scale, multi-company econometric models, like Chainalytics' Freight Market Intelligence Consortium (FMIC), which produce the required inputs from the market.

> ***A Closer Look at Potential Bias in Design Data***
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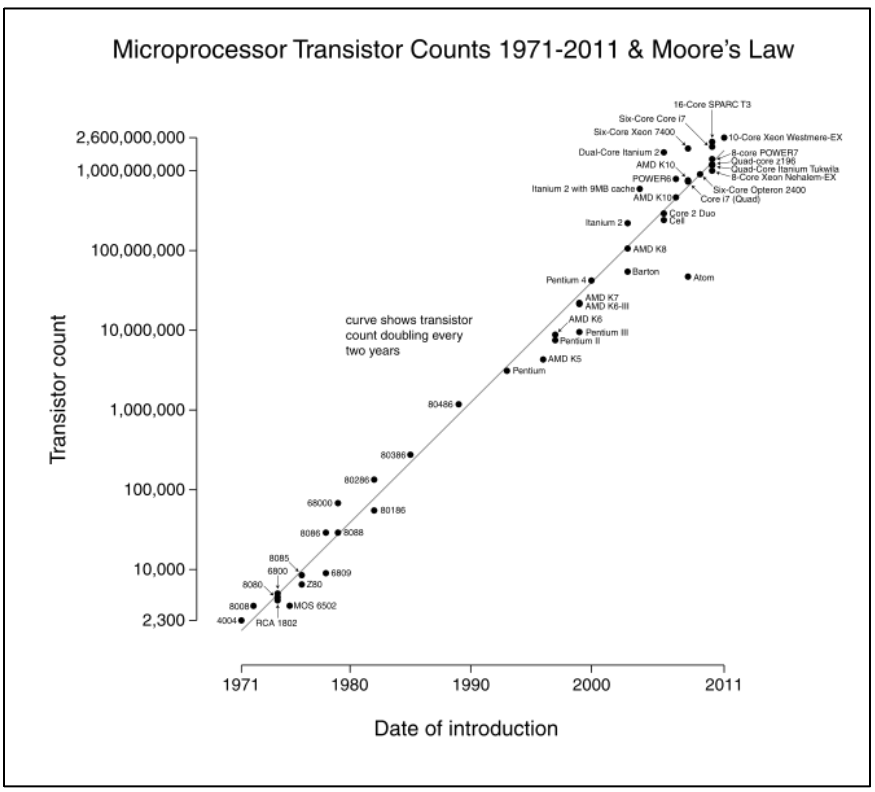
> *Design data plays an important role in Supply Chain Design. For example, consider a model in which all of the existing transportation lanes use actual costs (i.e. heavily negotiated rates). Meanwhile, the new or potential lanes just have a carrier's general estimate, and are not negotiated at all. The model would run, but it would choose all the existing lanes (because they are cheaper), incorrectly re-enforcing the current state. The team might be happy because the model says they're doing a great job, and have an optimal supply chain, but it would be very wrong.*

- **Modeling tools** have become sophisticated, yet still easy to use. Some of the important strides that have been made include: Support for multiple objective functions, the coupling of optimization and simulation in a single application, automated sensitivity analysis, math formulation and solver improvements, and usability improvements that have reduced the barriers to entry for inexperienced users.

Figure 2: Moore's Law



The increasing availability of computing power as described by Moore's Law has significantly enhanced the complexity, accuracy, and adoption of computer-enabled supply chain design.

These advances have pushed the boundaries of Supply Chain Design beyond “Network Optimization” into far more complex and valuable analyses about specific manufacturing lines, near-shoring or re-shoring, seasonal production plans, omni-channel distribution, the building of seasonal inventory, global tax strategies, item-specific flow-path design, and the consideration of GHG emissions and other sustainability factors.

Conclusion

The world is becoming more complex. Change is accelerating. Companies need to be able to formulate strategies which deal with such external factors as the change in oil prices, natural and man-made disasters, and their customers’ increasing service expectations.

Using sophisticated modeling techniques and tools, like MIP, companies are making better, fact-based decisions more quickly that require fewer resources to make and move their products to market. In the world of Supply Chain Design, being more efficient not only means cheaper, but greener as well. The more accurate and detailed Supply Chain Design models become, the easier it will be to reduce cost and waste.

And, this is only the beginning. These tools and techniques have made tremendous strides in the past few decades, but they are still in their infancy. Software companies and practitioners are currently pushing the envelope on the size of model that can be solved, addressing more and more of today’s complexity.