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Teaching Supply Chain Analytics—From Problem Solving to Problem Discovery

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Abstract Mainstream teaching of supply chain analytics focuses on model-driven predictive and prescriptive analytics to solve problems. Data-driven descriptive and diagnostic analytics to define and discover problems is almost entirely missing from the curriculum. The reason, as some believe, is that the latter is easier and of a lower value. But, in the words famously attributed to Steve Jobs, "If you define the problem correctly, you almost have the solution." Problem discovery by descriptive and diagnostic analytics is not only highly valuable but can also be difficult—it is just difficult in a different way from problem solving. One key challenge is data interpretation—that is, transforming data into insights: *INFORMS's definition of analytics*. In this tutorial, I summarize recent development and education modules that use descriptive and diagnostic analytics to define and discover problems based on data in various supply chain domains from source, make, move, and sell to integration. I showcase the value and methodology using inventory analytics, sourcing analytics, and competitive intelligence.

Keywords supply chain management • analytics • teaching • inventory analytics • sourcing analytics • competitive intelligence • benchmarking

1. Introduction

Davis [4] summarizes four types of analytics and their questions answered, from easy to difficult and from low value to high value as descriptive, diagnostic, predictive, and prescriptive analytics. Descriptive and diagnostic analytics uses data to discover problems and their causes, and it is primarily data-driven. Predictive and prescriptive analytics uses mathematical models to predict the future and solve problems, and it is primarily model-driven.

Most educational programs in supply chain analytics and management (either undergrad or graduate, either in the United States or beyond) focus on predictive and prescriptive analytics. Descriptive and diagnostic analytics, which is data-driven problem discovery, is almost entirely missing from the curriculum. The reason, as Davis [4] points out, may lie in the belief that descriptive and diagnostic analytics is relatively easy and less valuable. Is this true?

Some people thought otherwise. According to Albert Einstein, if he had an hour to solve a problem, he'd spend 55 minutes determining the proper question to ask, for once he knew the proper question, he would be able solve the problem in less than 5 minutes (quoted in Debevoise [5]). Charles Kettering, American inventor, engineer and businessman, who headed research in General Motors during 1920–1947, said, "A problem well defined is a problem half solved" (quoted in Kalisha [8]). Clearly, at least for some people, problem definition and discovery are far more challenging and important than problem solving.

After discovering and solving many problems in practice, I found that problem discovery by descriptive and diagnostic analytics is not only highly valuable but may also be difficult. It is difficult in a different way from problem solving. One key challenge is data interpretation, that is, how to extract useful information from data to make a business sense? This is consistent with INFORMS's definition of analytics: "Transforming data into insights for making better decisions". Seeing the same data, people may have different interpretations. The question is, do we really understand the data? In what follows, I use three examples to showcase the value and challenge of data interpretation.

2. Three Examples of Data Interpretation

2.1. Compaq vs. Dell

The first example is Compaq versus Dell. Around the year 2001, Compaq was the market leader in computer manufacturing with the largest market share. It also had a healthy cash flow and many patents. But surprisingly, Compaq sold itself and completely abandoned its strong brand. Why? To answer this question, we need to understand the computer industry background. Computer companies have the same key suppliers and technologies, such as CPU and operating system, for example. They were primarily competing on customer services and cost structure.

Table 1 shows the data. If we truly understand the data, we will know why Compaq sold itself. The data show that Compaq had a higher gross margin at 23.18% than Dell, which was at 20.62%. But Compaq's sales, general, and administrative (SG&A) cost was also higher—14.25% of its sales, compared with Dell's 10.08%—because Dell could manage inventory more effectively. In the end, Dell outperformed Compaq by about 1.5% in operating margin. This raises the question: Why is this 1.5% so critical that Compaq, the market leader, gave up the competition and sold itself?

This question troubled me for many years until one day when I suddenly understood the data and saw why Compaq sold itself. To see the answer, we must first explain why Compaq had a higher gross margin than Dell. The different gross margins can only be explained by a combination of two factors: different cost of goods sold (COGS) and pricing. Recalling that the computer companies had the same key suppliers; thus the different gross margins imply mainly different pricing. In fact, Dell had, on average, a 10% lower selling price than Compaq at that time. Even with lower pricing, Dell could make more profit—how could Compaq compete?

The Compaq versus Dell example is a classical one that happened a long time ago. A more recent example is the Taiwan Semiconductor Manufacturing Co. (TSMC) versus Intel. In 2020, TSMC was invited by the U.S. government to open a new five-nanometer chip factory in Arizona (Kharpal [10]). The news immediately raised a question: Doesn't the United States have the best semiconductor manufacturers in the world, such as Intel, Qualcomm, and Texas Instruments? Why was TSMC invited?

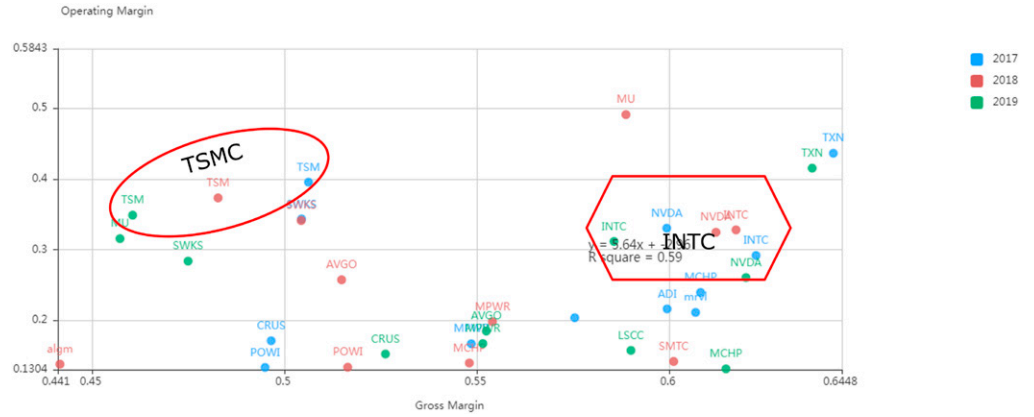
The answer lies in the data. A value driver analysis between the gross margin and operating margin for the semiconductor industry in the United States and Taiwan during 2017–2019 reveals an amazing story (Figure 1). Usually, gross margin and operating margin move together in the same direction; that is, if one company has a higher gross margin, it tends to have a higher operating margin. But if you can find a counterexample, then you may discover an extraordinary case similar to that of Compaq versus Dell. In Figure 1, we can see that Intel

Table 1. Compaq vs. Dell in 2000.

Company	Gross margin (%)	Inventory/revenue (%)	SG&A/revenue (%)
Compaq	23.18	5.32	14.25
Dell	20.62	1.42	10.08

Source. Yahoo Market Guide 2000.

Figure 1. (Color online) Value driver analysis of semiconductors industry in the United States and Taiwan in 2017–2019.



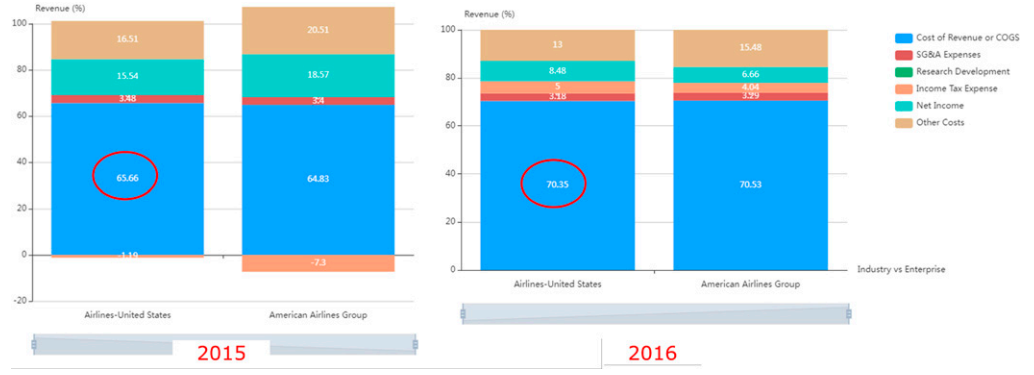
Source. Zhao [17, slide 21]; developed by SCDATA.ai. See https://SCDATA.ai.

(INTC) had a higher gross margin (in the neighborhood of 60%) than TSMC had (~50%). Given similar suppliers for semiconductors' raw materials and equipment, the difference in the gross margins of TSMC and Intel can mainly be explained by different pricing. Even with a higher pricing, Intel made less operating margin than TSMC. In summary, Intel may not be another Compaq because of its technological innovations. But, clearly, TSMC had a better operating efficiency than Intel and used it to offer better pricing, which partially explains the U.S. government's invitation.

2.2. U.S. Airlines

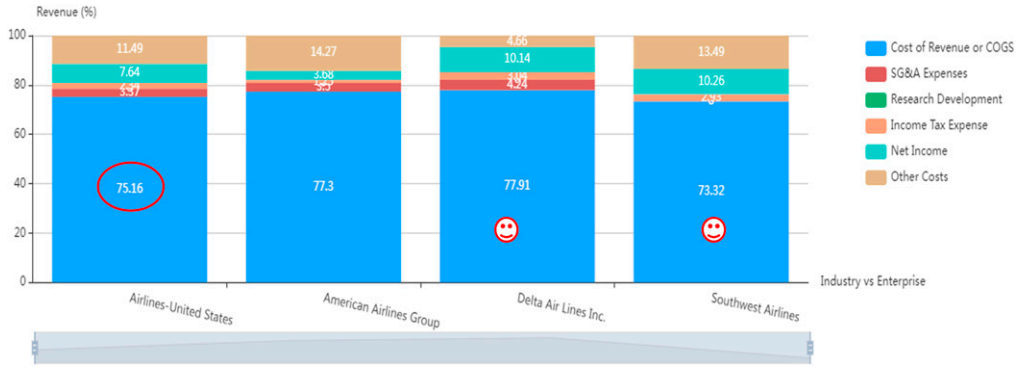
The second example is the airline industry in the United States. Warren Buffett made a famous quote about airlines: "The worst sort of business is one that grows rapidly, requires significant capital to engender the growth, and then earns little or no money. Think airlines" (quoted in Kaul [9]). How did he draw such a conclusion? Let's check out the data (Figure 2), which show that in 2015, the COGS of the U.S. airline industry averaged 65%, and the net margin was 15.5%. One year later, in 2016, the COGS rose to 70%, and the net margin was down to 8.5%.

Figure 2. (Color online) Revenue breakdowns of the U.S. airlines in 2015 and 2016.



Source. Zhao [17, slides 29, 30]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 3. (Color online) Revenue breakdowns of the U.S. airlines in 2019.



Source. Zhao [17, slide 26]; developed by SCDATA.ai. See https://SCDATA.ai.

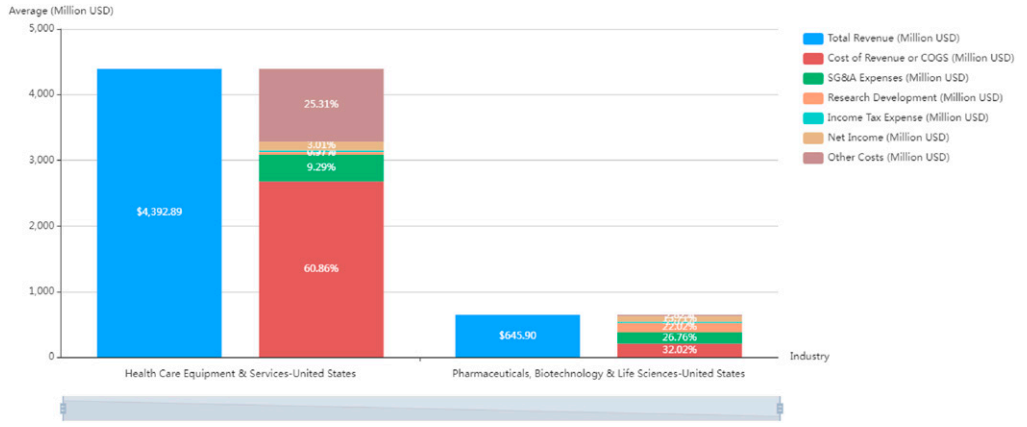
Three years later in 2019 (Figure 3), the COGS further rose to 75%, and net margin was down to 7.6%. One can feel the pressure of making profit in this industry, and the industry's performance during the COVID-19 pandemic was even worse. However, not every airline was a bad choice for investment. For example, Delta and Southwest performed above average on net margin using different strategies: Delta had excellent control over its assets and interests and thus had much lower "other costs,"[1] whereas Southwest had an excellent control over its COGS.

2.3. The Healthcare Sector

The third example is the U.S. healthcare sector, which was heavily criticized during the COVID-19 pandemic for its (overseas) outsourcing and the resulting supply disruptions. The industry, however, was arguing over the benefits of outsourcing such as cost reduction.

To justify the decision of outsourcing (overseas), let's compare two industry groups within the healthcare sector: (1) the healthcare equipment and services group and (2) the pharmaceuticals, biotechnology, and life sciences group for the United States in 2019 (Figure 4). We

Figure 4. (Color online) Healthcare equipment and services vs. pharma, biotech, and life sciences: outsource or not?



Source. Zhao [19, slide 7]; developed by SCDATA.ai. See https://SCDATA.ai.

can see that the former had a cost structure similar to a manufacturing or transportation industry, where the COGS accounted for 60% of the revenue, SG&A 9%, and net margin 3%. It makes sense to outsource (overseas) for a lower COGS in this industry group because its COGS accounts for such a high proportion of the revenue. By contrast, the pharmaceuticals, biotechnology, and life sciences industry group is a different story, where the COGS accounted for 32%, SG&A 27%, and net margin 9%. Outsourcing overseas for this industry group may not bring any total cost reduction because doing so also increases SG&A, which is almost as important as COGS.

This insight is more evident if we further look into the pharmaceuticals, biotechnology, and life sciences industry group. Data not illustrated here show that the biotech industry has an average COGS 17% of the revenue and SG&A 34%. So outsourcing overseas for a lower COGS in the biotech industry is unlikely to achieve the goal of total cost reduction, but it may bring a higher supply risk and total cost.

2.4. Value and Challenge of Descriptive and Diagnostic Analytics

The three previous examples showcase the value and challenge of data interpretation by descriptive and diagnostic analytics. A wealth of education modules have been developed and implemented to discover and solve problems in various supply chain domains from source, make, move, and sell to integration (Zhao [16]). For example (see Figure 5), competitive intelligence and benchmarking can discover a company's strengths and weaknesses relative to its competitors to identify its problems and causes. Demand forecasting and planning for vaccine supplies should align commerce with public health for better preparation for pandemics. Sales and operations planning can help to build a logistics network design model that is Excel solvable in seconds. Distribution analytics using descriptive and diagnostic analytics has helped a major U.S. wireless carrier save $1 billion in inventory investment (Zhao [13]). Inventory analytics can help users discover inventory problems by answering questions such as, is inventory important to me? How does inventory drive the financial performance in my industry? How do I know if I have an inventory problem?

In addition, we find impactful applications of descriptive and diagnostic analytics on sourcing—namely, sourcing analytics—as a typical company may spend hundreds of millions of dollars on tens of thousands of stock-keeping units (SKUs) bought from thousands of suppliers, which is a promising area for both research and teaching. Finally, instructional games and simulations based on data analysis can be inspiring and engaging, especially for online teaching—for example, panic orders and hoarding under supply shortages can be explained using the Hunger Chain Simulation ("Hunger Game"), and supply chain contracts and collaboration are discussed in the FloraPark Simulation ("Flower Game") (Zhao [16]).

In what follows, I shall dive into inventory analytics, sourcing analytics, and competitive intelligence to showcase the value and methodology of data-driven descriptive and diagnostic analytics.

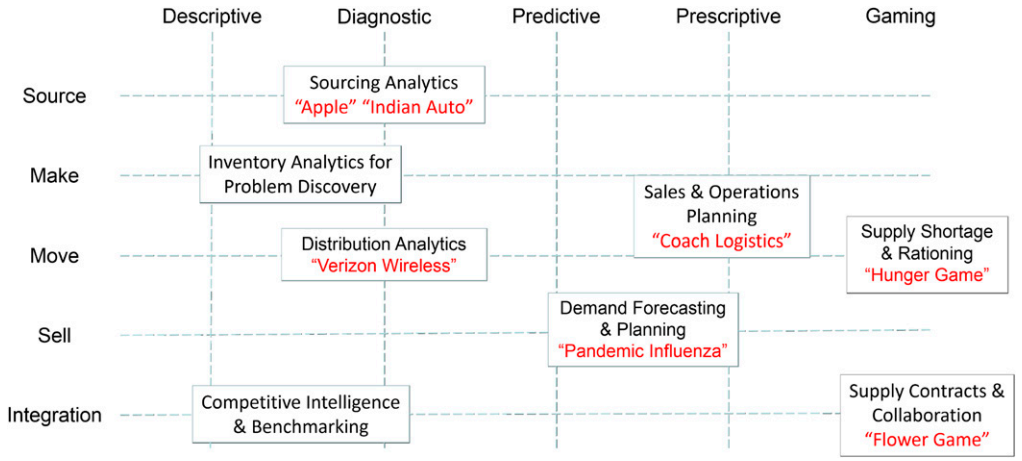
3. Inventory Analytics

Regarding inventory, the first thing that comes to mind for many people would likely be economic order quantity or newsvendor models. However, inventory analytics is different from inventory models because its primary objective is to discover inventory problems by asking three questions:

1. For which industries is inventory important?
2. How may inventory drive a firm's financial performance in my industry?
3. How do I know if I have an inventory problem?

First and foremost, one must know if inventory is important in its company or industry to determine whether inventory is even relevant and would ever be of concern. For instance, inventory can be completely irrelevant to banks and many financial institutions, as they carry

Figure 5. (Color online) Applications of data-driven descriptive and diagnostic analytics.



zero inventory. Second, one would only need to manage inventory if doing so improves its financial performance—for example, increasing sales or reducing cost. Thus, the second question helps us to understand the financial impact of inventory before we start to manage inventory. The third question makes sense because a company may be already at or close to the optimum and thus have little room for further improvement, whereas another company may have huge room for improvement. The methodology of answering these questions lies in benchmarking, which relies on extensive data of the companies and industries.

3.1. For Which Industries Is Inventory Important?

To assess the importance of inventory in an industry, we can use two metrics: (1) inventory over total assets and (2) inventory turnover or inventory days. The definition of inventory over total assets is simply the inventory investment divided by total assets. Clearly, the higher the inventory as a percentage of the total assets, the more important inventory is. Inventory turnover and days are respectively defined as follows:

$$\text{Inventory turnover} = \text{Annual COGS} / \text{Inventory investment}$$
$$\text{Inventory days (DOS)} = \text{Number of business days in a year} / \text{Inventory turnover.}$$

Intuitively, inventory turnover implies for how many times inventory is sold and replaced in a year; inventory days implies the average days for which the item is held in inventory. Generally speaking, inventory management is more important for industries with a smaller inventory turnover or longer inventory days.

We showcase the benchmarking methodology by comparing selected industries between the United States and China in the reporting year 2019 (reporting dates in July 2019–June 2020). Figure 6 shows that, by median, inventory accounts for a negligible portion of the total assets in banks, software and services, and real estate industries in the United States, and thus inventory is quite irrelevant for them. On the contrary, retailing has 24% of the total assets in inventory by median and thus is an industry for which inventory can be a serious concern. The consumer durables and apparel industry has a slightly lower median of 23% but a significantly higher 90th percentile of 73%, and thus it is another industry in which inventory plays a critical role. It is followed by the automobiles and components and food and staples retailing industries.

For the same industries, Figure 7 provides the data for China, which illustrate some similarities and differences. Similarities include a negligible inventory for banks and software and services industries and a significant inventory for retailing and consumer durables and apparel. The

Figure 6. (Color online) Inventory over total assets for selected industries in the United States in 2019.

Benchmark by KPI - Inventory / Total Assets

Industry	90th Percentile	75th Percentile	Median	25th Percentile	10th Percentile
Capital Goods-United States	0.35	0.22	0.13	0.08	0.04
Automobiles & Components-United States	0.41	0.27	0.17	0.08	0.05
Consumer Durables & Apparel-United States	0.73	0.37	0.23	0.13	0.07
Retailing-United States	0.44	0.34	0.24	0.13	0.07
Food & Staples Retailing-United States	0.28	0.21	0.14	0.1	0.06
Food, Beverage & Tobacco-United States	0.43	0.22	0.12	0.06	0.03
Banks-United States					
Software & Services-United States	0.14	0.05	0.01	0	0
Technology Hardware & Equipment-United States	0.35	0.22	0.13	0.07	0.03
Semiconductors & Semiconductor Equipment-United States	0.22	0.16	0.1	0.06	0.04
Real Estate-United States	0.2	0.06	0.01	0	0

Source. Zhao [18, slide 26]; developed by SCDATA.ai. See https://SCDATA.ai.

most noticeable difference is that, by median, the Chinese real estate companies have 35% of the total assets in inventory compared with 1% for its U.S. counterpart. Thus the answer to the question of "in which industries is inventory important?" is clearly dependent on the country.

From a different angle, inventory days, we can see how serious the inventory problem is for the Chinese real estate companies (Figure 8). The median inventory days of (publicly traded) real estate companies in China climbed way over 1,200 days during the 2018–2020 reporting years and resulted in a median cash conversion cycle approaching 1,000 days. By comparison, real estate companies in the United States have a median inventory days of less than 40 days and a cash conversion cycle of about −120 to −140 days (which suggests a healthy cash flow: they received payments from their customers 120–140 days before they paid their suppliers).

3.2. How May Inventory Drive a Firm's Financial Performance?

The impact of inventory on companies' financial performance, such as profitability and investment returns, is one central question in inventory management, but it is only partially answered in the literature and practice. For example, Chen et al. [2, 3] empirically studied the inventories of publicly traded American manufacturing, retailing, and wholesale companies

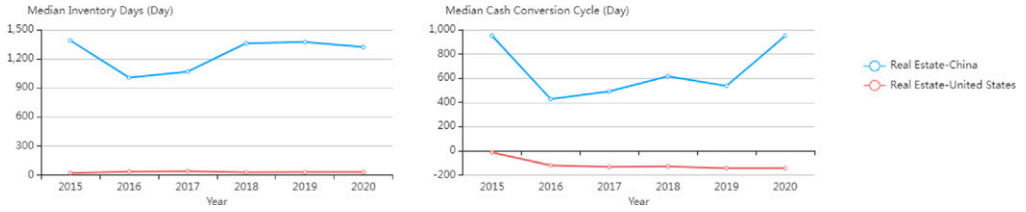
Figure 7. (Color online) Inventory over total assets for selected industries in China in 2019.

Benchmark by KPI - Inventory / Total Assets

Industry	90th Percentile	75th Percentile	Median	25th Percentile	10th Percentile
Capital Goods-China	0.28	0.19	0.14	0.08	0.04
Automobiles & Components-China	0.2	0.15	0.11	0.08	0.05
Consumer Durables & Apparel-China	0.3	0.22	0.14	0.09	0.04
Retailing-China	0.37	0.25	0.13	0.04	0.01
Food & Staples Retailing-China	0.32	0.24	0.15	0.07	0.02
Food, Beverage & Tobacco-China	0.29	0.21	0.13	0.07	0.04
Banks-China					
Software & Services-China	0.18	0.11	0.05	0.01	0
Technology Hardware & Equipment-China	0.23	0.17	0.12	0.08	0.05
Semiconductors & Semiconductor Equipment-China	0.24	0.16	0.09	0.05	0.03
Real Estate-China	0.68	0.55	0.35	0.09	0

Source. Zhao [18, slide 28]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 8. (Color online) Median inventory days and cash conversion cycle for the real estate sector in the United States and China.



Source. Zhao [18, slide 33]; developed by SCDATA.ai. See https://SCDATA.ai.

during 1981–2000 and discovered trends of inventory performance, as well as certain correlations between inventory performance and stock returns. Gaur et al. [7] provided empirical justification for the negative correlation between inventory turnover and gross margin for the U.S. retailing industry during 1987–2000.

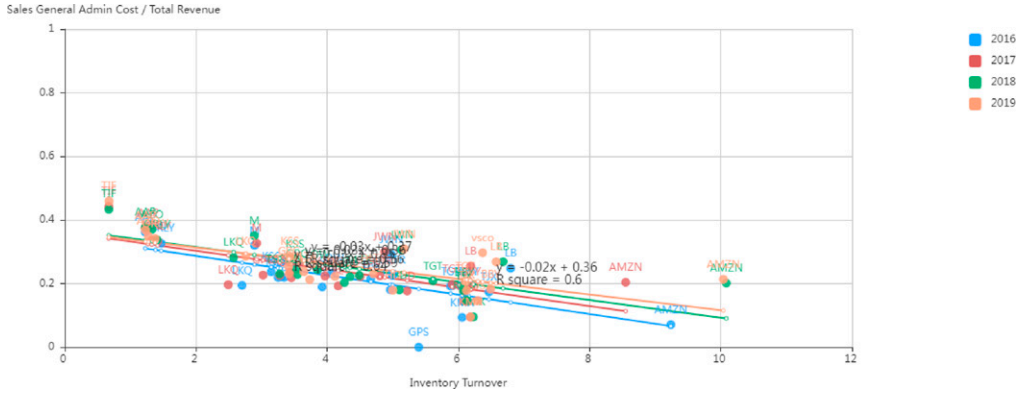
Value driver analysis is a general-purpose data analysis tool to identify potential factors that may drive a company's performance in an industry. One can examine correlations between driving factors (e.g., inventory turnover) and financial performance (e.g., return on assets) to identify potential drivers or levers. Selecting S&P 500 retailing companies in the United States, a value driver analysis shows a strong negative correlation ($R^2 = 60\%$) between inventory turnover and SG&A cost over total revenue for each of the four years from 2016 to 2019 (Figure 9). The result implies that a higher inventory turnover may lead to a lower SG&A cost over total revenue for the U.S. retailing industry.

Note that such a correlation may not exist for industries other than retailing or countries other than the United States. In fact, the driving factors are often hidden in a vast amount of data and can vary by industry, country, and time. That being said, discovering value drivers and levers for your industry can be highly valuable and need to be uncovered by analysts and researchers in a timely fashion.

3.3. How Do I Know If I Have an Inventory Problem?

Although this question is rarely asked by people in academia, it makes perfect sense in practice before one starts to work on inventory. One must know how much room there is for

Figure 9. (Color online) Inventory turnover vs. SG&A/total revenue for the U.S. retailing S&P 500 companies.



Source. Zhao [18, slide 37]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 10. (Color online) Benchmarking inventory days for select U.S. industries in 2019.

Benchmark by KPI - Inventory Days (Day)

Industry	90th Percentile	75th Percentile	Median	25th Percentile	10th Percentile
Capital Goods-United States	172.29	109.68	72.57	44.42	20.32
Automobiles & Components-United States	404.92	119.52	63.72	42.64	24.58
Consumer Durables & Apparel-United States	356.96	188.34	114.2	76.49	45.14
Retailing-United States	189.16	128.86	85.72	56.49	27.4
Food & Staples Retailing-United States	55.23	41.1	31.9	26.28	15.8
Food, Beverage & Tobacco-United States	296.64	128.65	66.47	45.29	28.86
Household & Personal Products-United States	598.21	238.37	133.83	87.25	46.76
Pharmaceuticals, Biotechnology & Life Sciences-United States	702.19	291.68	149.94	72.32	31.72
Technology Hardware & Equipment-United States	213.68	132.2	83.04	50.62	26.38
Semiconductors & Semiconductor Equipment-United States	273.82	154.22	110.19	75.22	45.45

Source. Zhao [18, slide 27]; developed by SCDATA.ai. See https://SCDATA.ai.

improvement in inventory. The answer lies in benchmarking—specifically, if my revenue is half of yours, but I hold the same amount of inventory as you do, then I must have an inventory problem!

For example, Figure 10 shows that the (publicly traded) U.S. retailing companies had a huge variation in inventory days where the 90th percentile (i.e., worst performance), 189 days, is 6 times the 10th percentile (i.e., best performance), 27 days. Clearly, if a retailer's inventory days is close to the best performance (e.g., Amazon at 36 days), there is little room for further improvement. But if a company is in the neighborhood of the worst performance (e.g., Macy's at 125 days), it surely has an inventory problem. The same observation can be made for food and staple retailing, where the worst performers had two months of inventory but the best performers had only half a month of inventory. The opportunity for pharmaceuticals, biotechnology, and life sciences companies is even greater, with the worst performance being 23 times that of the best performance.

4. Sourcing Analytics

Sourcing is highly data driven for two reasons: (1) New suppliers and products constantly emerge, and corporations are subject to constant changes (e.g., mergers and acquisition, bankruptcy), which requires a frequent adjustment of the supply base. (2) A typical company may spend millions of dollars on hundreds of thousands of SKUs bought from thousands of suppliers. Thus, there is a tremendous value to be harnessed by data analytics in sourcing—that is, sourcing analytics—which consists of four areas:

1. *Sourcing intelligence*: to identify and select new suppliers.
2. *Spend analysis and strategic sourcing*: to balance the risk and cost trade-off between consolidation to reduce cost and diversification to reduce risk.
3. *Supplier management and development*: to track supplier performance and ensure contract compliance.
4. *Buying process and buyer management.*

Because of space limitations, we shall focus on sourcing intelligence in this chapter. Sourcing intelligence consists of three components: market intelligence, bargaining power analysis, and supplier analysis. It starts by determining the company's needs and supplier selection criteria. Then it proceeds to analyzing the supply markets to identify the potential suppliers and their offerings. Finally, it provides quantitative insights to support better negotiation and bargaining with the suppliers. I will use the example of Apple's iPhone to showcase the methodology and impact of sourcing intelligence.

iPhone was highly profitable for Apple at its introduction partially because of its global sourcing strategy (Rafique et al. [11]). In fact, from 2007 to 2010, Apple made $27 billion from iPhone with a profit of $15.6 billion. Apple designed and sold the iPhone but completely outsourced its manufacturing to companies such as Samsung Electronics for processors and Samsung and Intel for flash memories. The results were phenomenal: Apple's gross profit was $333 with a retail price of $599. However, Samsung Electronics soon became a competitor to Apple by introducing its own smartphones and using its cost advantage to overtake Apple in the global market. Meanwhile, many new suppliers and products are emerging constantly. Apple needs to continue its success by exploring the supply markets of critical components such as processors and memories and identify and select new suppliers.

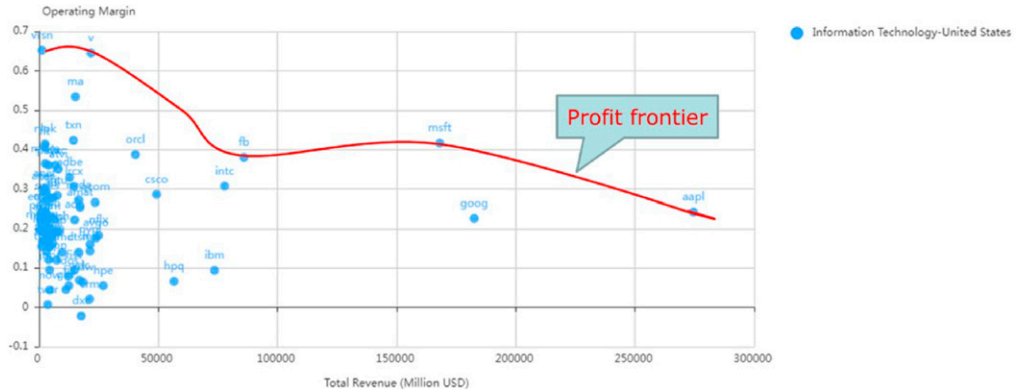
4.1. Setting Supplier Selection Criteria

Apple must first determine its needs and goals by understanding its competitive strengths and weaknesses and then set supplier selection criteria accordingly. For instance, looking at the S&P 500 U.S. information technology companies, including both hardware and software (Figure 11), we found that Apple was leading the way in total revenue but not in profit because its (operating) margin was clearly lower than that of Microsoft, Facebook, and Visa.

Looking into the revenue breakdown of the technology hardware, storage, and peripherals industry (including smartphone providers such as Apple Inc.), we can see that the industry's average COGS accounted for 66% of its revenue. With 62%, Apple was doing better than the industry average, but COGS (especially purchasing cost as Apple did little manufacturing by itself) was still the major cost driver. In summary, CPU supplier selection criteria for iPhone would have four categories of conditions:

1. *Capability:* The supplier should be innovative, should be technologically and engineering capable, and have sufficient manufacturing capacity and high quality.
2. *Cost:* The supplier should offer a good price to Apple and, despite this, still make a good profit. In addition, it would be ideal if Apple has more bargaining power than the supplier.
3. *Continuity:* The supplier should have rock-solid financial health and flexible and responsive to demand.
4. *Competition:* The supplier should not leak sensitive information (such as a trade secret) or become a potential competitor.

Figure 11. (Color online) Profit frontier for S&P 500 U.S. information technology companies in 2020.



Source. Zhao [20, slide 12]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 12. (Color online) Map for enterprise distribution—semiconductors in 2020.

Source. Zhao [20, slide 20]; developed by SCDATA.ai. See https://SCDATA.ai.

Data analytics can help in examining the market and suppliers and provide insights on how these criteria (conditions) are met or not met.

4.2. Market Intelligence

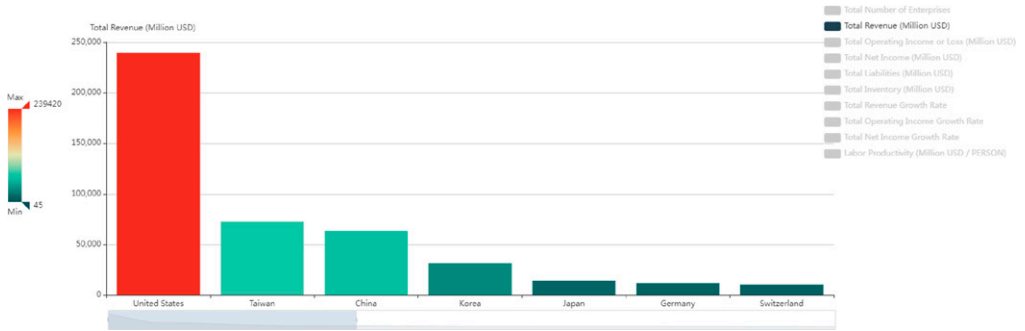
The objective of market intelligence is to identify potential suppliers by analyzing the global supply markets to obtain insights from business geographic information, the competitive intensity of the market, and market trend and stability.

We first use business geographic information to identify potential supplying countries globally. Displaying company information on a map (Figure 12), we find that the countries with the highest total revenue in semiconductors in 2020 were the United States, China, Taiwan, Korea, and Japan. From the bar chart (Figure 13), we can see more clearly the quantitative difference: the United States was clearly leading the way in the semiconductors industry, which was followed by Taiwan, China, Korea, and Japan.

In addition to the total revenue, we look at the total revenue growth of the semiconductor industry by country (Figure 14). As a general rule, countries with a higher total revenue usually grow slower. However, we found that Taiwan and Korea, which had the highest total revenue in semiconductors, also had the highest growth. In what follows, we choose to focus on three countries for semiconductor suppliers: the United States, Taiwan, and Korea.

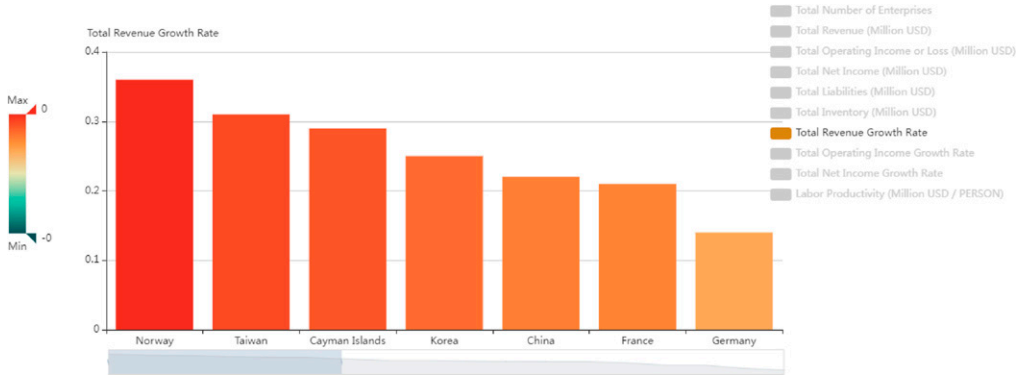
Now let us do a market share analysis to see the competition intensity (competitive or monopolized) of the market and the stability of the major players. The concentration and

Figure 13. (Color online) Bar chart for enterprise distribution—semiconductors in 2020.



Source. Zhao [20, slide 21]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 14. (Color online) Bar chart for enterprise distribution—semiconductors' growth in 2020.



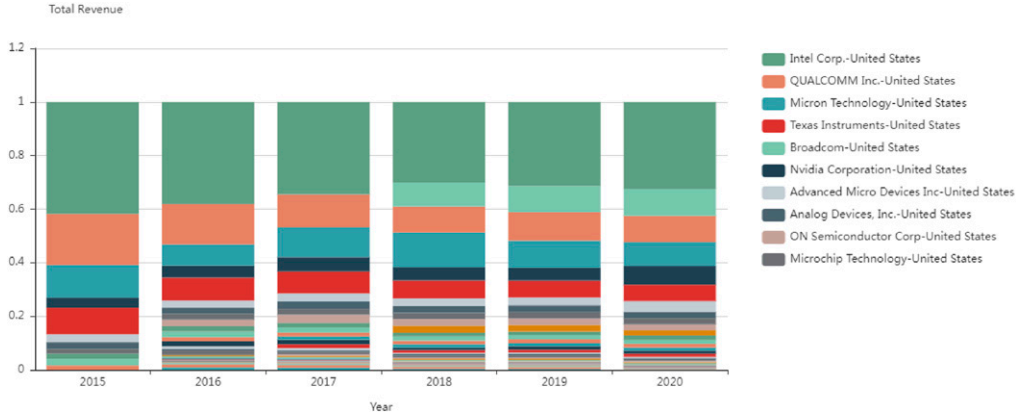
Source. Zhao [20, slide 22]; developed by SCDATA.ai. See https://SCDATA.ai.

competition intensity analysis of the semiconductor industry in the United States (Figure 15) shows that the market shares were stable, and the market was relative competitive, with a few whales and many smaller fish. The major players were Intel, Qualcomm, Micron, and Texas Instruments.

The net income analysis shows a different picture (Figure 16). Whereas Intel and Texas Instruments made a stable net income over the past few years, Qualcomm and Micron were quite variable. Indeed, Qualcomm's net income was negative in 2018, and Micron made a huge net income in 2018, which gradually decreased in 2019 and 2020.

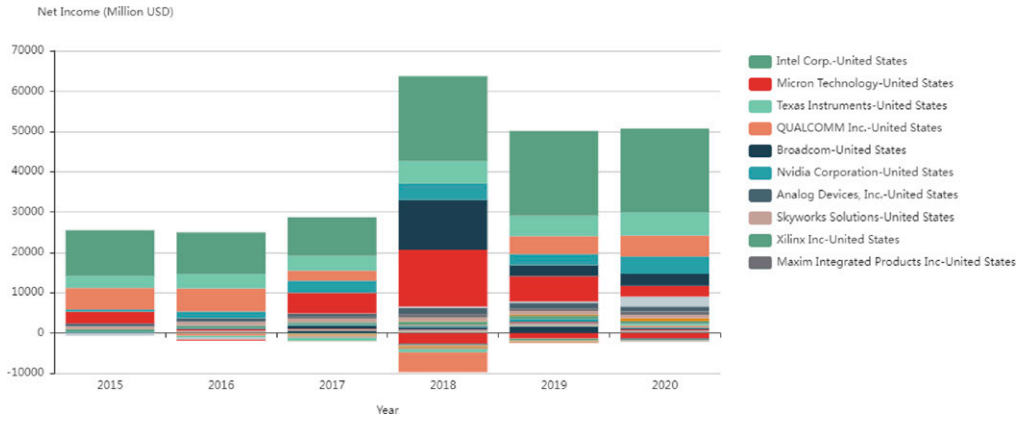
Following these analyses, we can pick a few potential suppliers for the CPU/processors of iPhone from a ranking of the publicly traded semiconductor companies in the United States, Taiwan, and Korea (Figure 17). As an example, we can select Intel, TSMC, and Qualcomm based on their size and GlobalFoundries to enhance supplier diversity. Samsung was a reliable processor supplier for Apple, so we include it as a benchmark, despite the leaks and competition issues (note that Samsung Electronics has a highly diversified business scope, which includes semiconductors, technology hardware, and household appliances, and thus it is not classified as a semiconductor company).

Figure 15. (Color online) Market share of the U.S. semiconductors industry in 2020.



Source. Zhao [20, slide 25]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 16. (Color online) Net income of the U.S. semiconductors industry in 2020.



Source. Zhao [20, slide 27]; developed by SCDATA.ai. See https://SCDATA.ai.

4.3. Bargaining Power Analysis

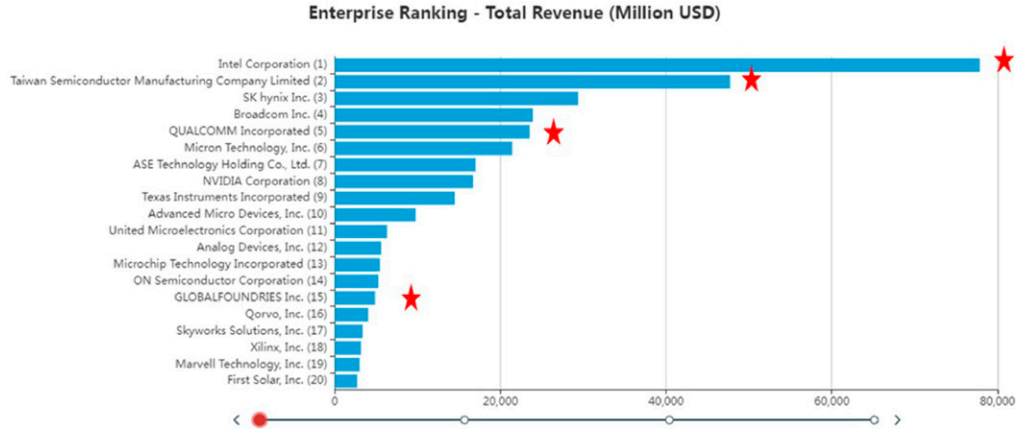
The objective of bargaining power analysis is to answer three questions:

1. What is my (buying) leverage?
2. What is my supplier's (selling) leverage?
3. Who has the bargaining power?

This knowledge is important in negotiation because you will know whether you or your supplier should concede in making the deal. We shall answer these questions by quantifying the leverages (either buying or selling) and calculating the bargaining power index, which measures the relative bargaining power.

In a general competitive market with multiple (>2) suppliers, we can use the bargaining power analysis to assess the leverages of the buyer and supplier. Intuitively, if I buy 50% of your volume, which is only 5% of my expenditure in this category, then I have bargaining power over you. For example, Walmart may buy a significant portion of the yearly output of

Figure 17. (Color online) Enterprise ranking by total revenue for semiconductors in the United States, Korea, and Taiwan in 2020.



Source. Zhao [20, slide 28]; developed by SCDATA.ai. See https://SCDATA.ai.

a small- or medium-size enterprise, which may only be a small fraction of what Walmart sells in this category. In this case, the buyer has the bargaining power because if there is no deal, the supplier loses 50% of its sales, whereas the buyer loses only 5% of the supply. Conversely, if I buy 5% of your volume, which is 50% of my expenditure in this category, then you have bargaining power over me. For example, Intel is the largest semiconductor manufacturer selling its microchips to many customers. Being a relatively small customer, Huawei heavily depends on Intel's chip supply for its notebooks and cell phones. In this case, the supplier has the bargaining power because if there is no deal, the supplier loses 5% of the sales, but the buyer loses 50% of the supply.

Following this intuition, we can calculate the leverages as follows: Consider a buyer, a supplier, and a category of materials. The buyer leverage can be measured by the buyer's spend on the supplier as a percentage of the supplier's sales or, equivalently, the buyer's contribution to the supplier's revenue. The supplier leverage is the buyer's spend on the supplier as a percentage of the buyer's total spend in the category or, equivalently, the supplier's supply to the buyer's category. Put mathematically,

$$\text{Buyer leverage} = \text{The buyer's spend on the supplier} / \text{The supplier's total sales};$$

$$\text{Supplier leverage} = \text{The buyer's spend on the supplier} / \text{The buyer's total category spend}.$$

We can define the bargaining power index to be the ratio between buyer leverage and supplier leverage:

$$\text{Bargaining Power Index (BPI)} = \text{Buyer leverage} / \text{Supplier leverage}.$$

Intuitively, if BPI $\ll 1$, the supplier has the bargaining power because the buyer needs the supplier more than the other way around. If BPI $\gg 1$, the buyer has the bargaining power because the supplier needs the buyer more than the other way around. If BPI ~ 1, the bargaining power is balanced: the buyer and supplier need each other equally.

As an example, we can do the bargaining power analysis for Apple with its major semiconductors suppliers. The 2016 data show that Apple's total semiconductors spend is \$15.7 billion, among which \$4 billion is spent on TSMC. The 2016 revenue of the suppliers is listed in Figure 18. The suppliers' leverage can be calculated by dividing Apple's spend on the supplier by Apple's total spend, so, for example, TSMC's leverage over Apple is \$4 billion/\$15.7 billion, which is 25.48%. Apple's leverage can be calculated by dividing Apple's spend on the supplier by the supplier's revenue, so, for example, Apple's leverage over TSMC is \$4 billion/\$29.2 billion, which is 13.69%. Finally, the BPI for TSMC and Apple is 0.54, which implies

Figure 18. (Color online) Bargaining power analysis of Apple with its semiconductors suppliers in 2016 (data from Edwards [6]).

Semiconductors	Apple spend \$M	Supplier Leverage	Supplier Revenue \$M	Apple leverage	BPI
IC total	15696.4				
KNOWLES	48.4	0.31%	440	11.00%	35.67
Imagination	74	0.47%	148	50.00%	106.06
DIALOG SEMICONDUCTOR	864	5.50%	1200	72.00%	13.08
CIRRUS LOGIC	960	6.12%	1200	80.00%	13.08
SKYWORKS SOLUTIONS	1450	9.24%	3289	44.09%	4.77
WESTERN DIGITAL CORP	1800	11.47%	14500	12.41%	1.08
QUALCOMM	1900	12.10%	23554	8.07%	0.67
TEXAS INSTRUMENTS	2000	12.74%	13370	14.96%	1.17
BROADCOM	2600	16.56%	13240	19.64%	1.19
TAIWAN SEMICONDUCTOR MANUFACTURING CO	4000	25.48%	29220	13.69%	0.54

that TSMC has bargaining power over Apple. A similar analysis shows that Apple had bargaining power over many suppliers such as Skyworks and Cirrus Logic, but Qualcomm also had bargaining power over Apple.

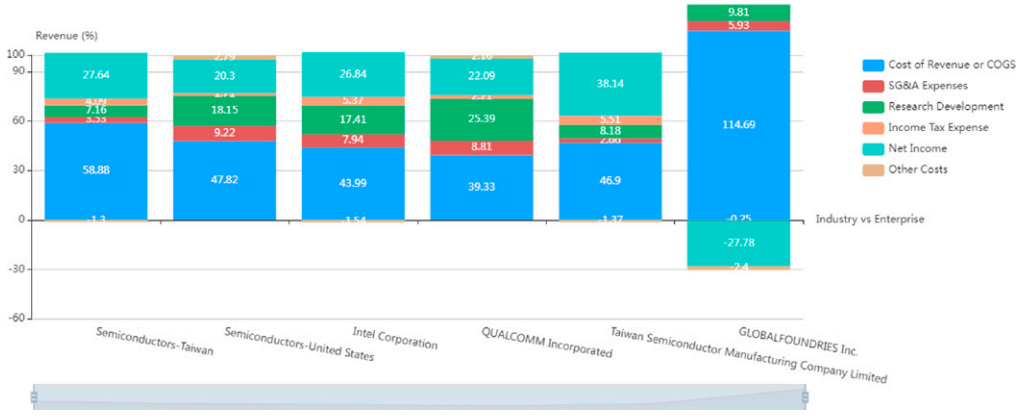
4.4. Supplier Analysis

The objective of supplier analysis is to analyze and compare individual suppliers in order to identify the best one(s) meeting the selection criteria. We use a pricing and profitability analysis to gauge the suppliers' prices, profitability, and technical capability. We use a financial health analysis to understand the suppliers' short- and long-term liabilities and risks, and we use an efficiency analysis to assess the suppliers' cost efficiency, flexibility, and responsiveness.

Innovation and technical competence of a company can be measured by its gross margin. A high gross margin implies a high value-added (innovation and/or technology, as well as high pricing) or a low COGS. For profitability, net margin is the best measure, where a high net margin implies a high profitability. The ideal supplier (for a long-term supply) is the one that, despite a lower pricing, is very profitable so that it can sustain the low pricing to its customers. A deceiving supplier (which may look good superficially) is one that offers customers a good price but can hardly make any profit from it. It is deceiving because, eventually, the supplier may go bankrupt, and the customers will have to pay a high price one way or the other.

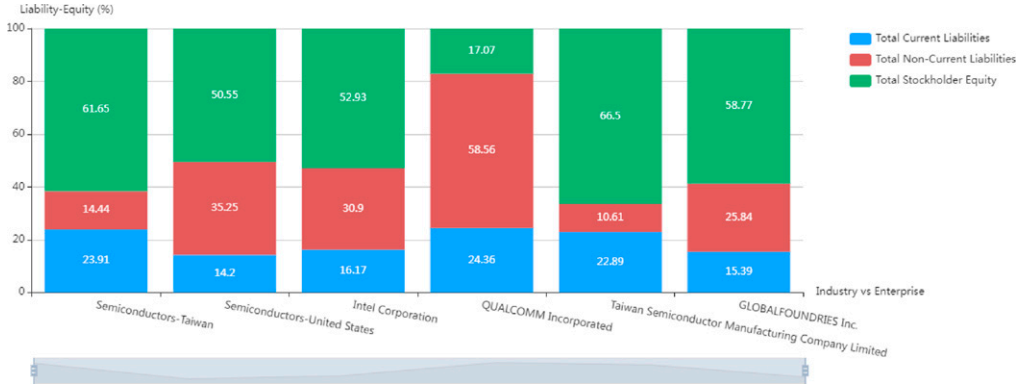
One way to analyze pricing and profitability is the revenue breakdown of the semiconductors industry for the United States and Taiwan (Figure 19), which shows that in 2020, Qualcomm had the highest gross margin and thus likely the highest pricing; it also had the highest spend on research and development (R&D) and made a sizable net income. TSMC had the lowest gross margin among the three (Intel, Qualcomm, and TSMC) and so likely the lowest pricing; it spent the least on R&D, the lowest on SG&A, and made the highest net margin. Intel was in between Qualcomm and TSMC. GlobalFoundries had a negative gross margin, and so its pricing and technical capabilities were unknown. Comparing Intel, Qualcomm, and TSMC, we can see that Qualcomm had the highest pricing (gross margin) but the lowest profitability (operating and net margins), TSMC had the lowest pricing (gross margin) but the highest profitability (operating and net margins), and Intel was in between. Thus TSMC was the ideal supplier from a pricing and profitability perspective among the three. An enterprise trend analysis (not shown here) from 2015 to 2020 confirms this observation for multiple years and further illustrates that Intel and TSMC had stable margins over time, but Qualcomm had more fluctuations in operating and net margins (e.g., Qualcomm's net margin is negative in 2018).

Figure 19. (Color online) Revenue breakdown of Intel, Qualcomm, TSMC, and GlobalFoundries in 2020.



Source. Zhao [20, slide 38]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 20. (Color online) Liability and equity assets breakdown analysis of semiconductors in 2020.



Source. Zhao [20, slide 44]; developed by SCDATA.ai. See https://SCDATA.ai.

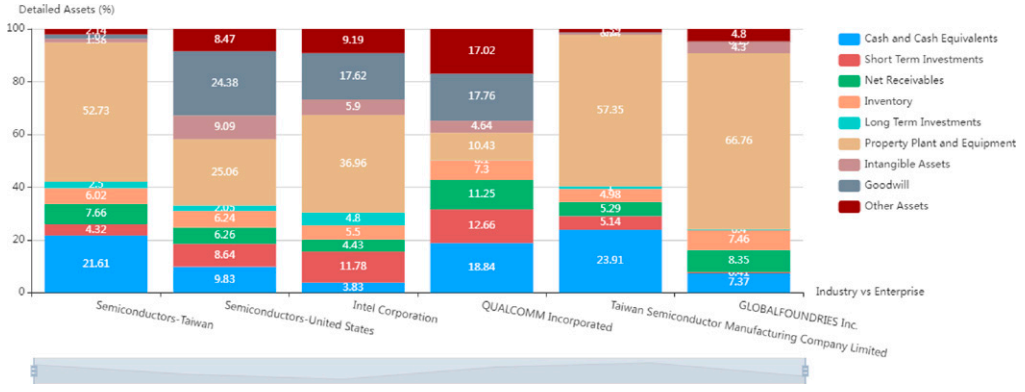
For critical components, Apple needs long-term suppliers with rock-solid financial health or stability. The major trap to avoid is the short-term good deal (e.g., in the form of a deep discount) from companies with poor financial health, which can lead to a long-term crisis.

Breaking down these companies' total assets by liabilities and stockholder equity (Figure 20), we can see that TSMC had the highest percentage of equity and lowest total liabilities. Qualcomm had significantly higher noncurrent liabilities than the others. Intel was healthy on equity and liabilities, with an equity > 50% of the total assets. Despite losing money, GlobalFoundries was very healthy in terms of equity and liabilities.

Breaking down each company's assets into details (Figure 21), we found that TSMC had the highest amount of cash and the second-largest property, plant, and equipment (PP&E), which implies a high production capacity and responsiveness. Intel had a decent production capacity but perhaps ran a bit low on cash. Qualcomm had a surprisingly low PP&E, putting its production capacity and responsiveness into question. GloablFoundries had the highest PP&E percentage—it had built up a strong production capacity and also had a good amount of cash.

Operating efficiency is an important factor to consider when selecting the suppliers because efficient suppliers can help customers reduce cost in the long run and can provide more flexibility and responsiveness in production and delivery. Operating efficiency can be measured by asset utilization, inventory, cash cycle, and SG&A cost. Asset utilization shows the ability to

Figure 21. (Color online) Detailed assets breakdown analysis of semiconductors in 2020.



Source. Zhao [20, slide 45]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 22. (Color online) Supplier score sheet for the CPU or processors of iPhone in 2020.

	Intel	Qualcomm	Global Foundries	TSMC	Samsung Electronics
Innovative, technological / engineering capability	Excellent	Excellent	?	Excellent	Excellent
Manufacturing capacity / quality	Excellent	Good	Excellent	Excellent	Excellent
Pricing	Fair	Poor	Excellent	Excellent	Excellent
Profitability	Excellent	Good	Poor	Excellent	Good
Bargaining power	Poor	Poor	Excellent	Fair	Fair
Financially healthy / robust	Excellent	Good	Good	Excellent	Excellent
Reliable / flexible / responsive	Good	Good	Good	Excellent	Excellent
Leaks & competition	Excellent	Fair	Excellent	Good	Poor

Source. Zhao [20, slide 57]; developed by SCDATA.ai. See https://SCDATA.ai.

generate more revenue or profit using the same amount of assets; inventory is a measure of efficiency in operations, as a low inventory often means tighter operational control, less waste, and higher product quality; the cash cycle, together with payables and receivable days, measures the market/negotiation power and the speed from raw materials to cash receipts; and finally, SG&A cost is related to selling and distribution efficiency. The interpretation is relatively straightforward, and thus we shall skip the details.

We can use supplier score sheets to summarize all the analysis so that we can compare potential suppliers side by side and select the best supplier(s) meeting the supplier selection criteria. For the CPU of iPhone, the supplier score sheet may look like Figure 22, which shows that TSMC has the most green (favorable) scores, Intel and Samsung have the second most favorable scores, and Qualcomm the third. GlobalFoundries needs to verify its technical capability; otherwise, it looks good as a potential supplier.

Based on the analysis, the sourcing strategy for the CPU or processors of iPhone would be to use TSMC as a main supplier; spread some work to Intel, Qualcomm, or Samsung for their specialties as minor suppliers; and cultivate GlobalFoundries as a potential supplier. This is largely what Apple has done in recent years, except for cultivating GlobalFoundries.

5. Competitive Intelligence

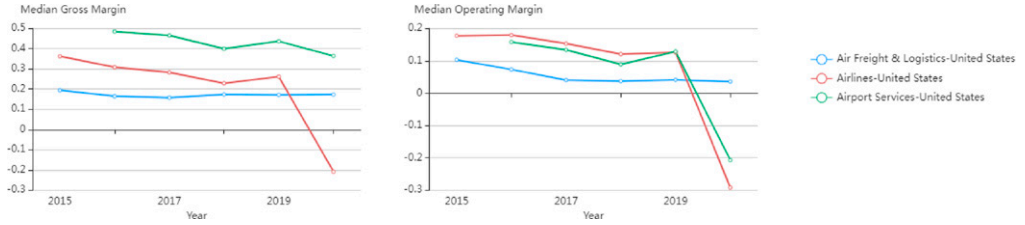
One of the top three skills in supply chain management is to see the big picture (Cecere [1]). Competitive intelligence (Wikipedia [12]) is a powerful tool based on benchmarking to discover problems and opportunities for a company and allows management to see which directions the company should be moving. In fact, many of the management consulting projects start out with a competitive intelligence analysis, which usually consists of the following elements:

1. Industry analysis (including industry trend, competition intensity, value chain analysis) to assess the industry potential and risk.
2. Competition positioning (e.g., profit frontier, enterprise ranking, key performance indicator (KPI) examination of a company—analogous to the physical examination of a person) to position a company in the competitive landscape.
3. Enterprise diagnosis (such as strengths and weaknesses, value driver analysis, breakdown analysis) to discover problems and identify causes.

Competitive intelligence can help answer the following questions:

- What are the market potential, risk, and entry barriers?

Figure 23. (Color online) Trend analysis of the U.S. airlines, air-freight, and airport services industries.



Source. Zhao [14, slide 14]; developed by SCDATA.ai. See https://SCDATA.ai.

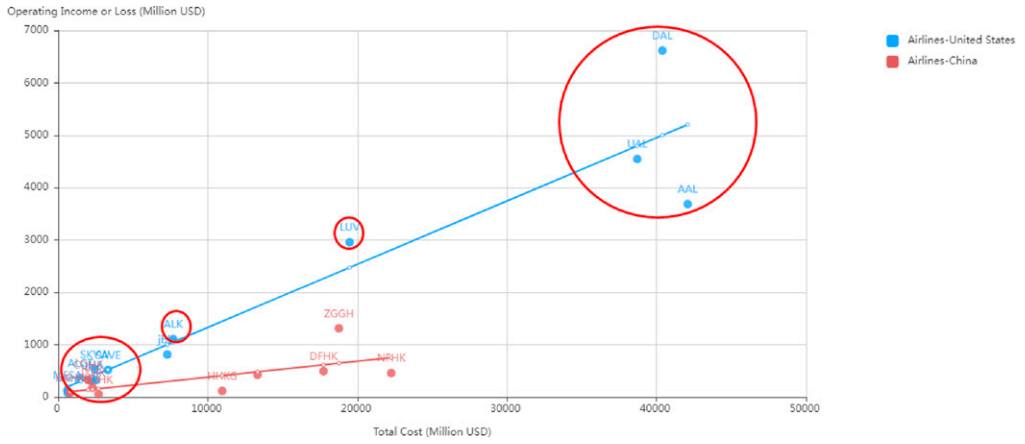
- Should I focus on my core business or diversify to up- or downstreams?
- Where do I stand in the competitive landscape?
- What are my strengths and weaknesses relative to my competitors?
- What factor(s) may drive a company's financial performance in my industry?
- What are my key problems and the causes?

The methodology and impact can be best illustrated by an example, American Airlines (AAL), which is the world's largest airline by fleet size, revenue, passengers carried, and number of destinations served in 2019. Despite its size, AAL was performing the worst in the stock market compared with its major competitors, such as United, Delta, and Southwest, and it was moving in the opposite direction from the S&P 500 index during 2014–2020. AAL was clearly in trouble, and it needed to discover the problems and causes and, based on this, to develop a strategy to turn the company and the stock price around.

The U.S. airlines suffered thin margins prior to the COVID-19 pandemic and serious losses during the pandemic. As Figure 23 shows, airlines were more profitable than air-freight companies before the pandemic. During the pandemic, however, airlines and airport services suffered significant losses while air-freight companies maintained a stable profitability.

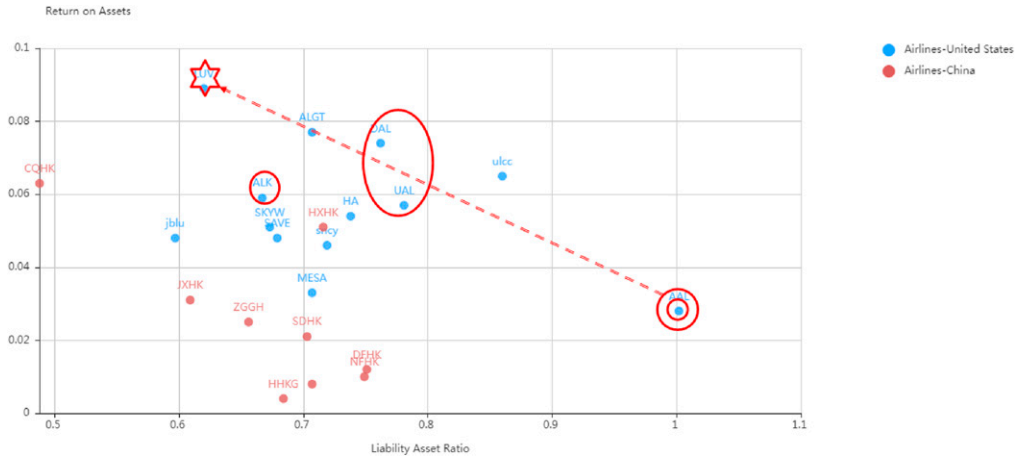
To position AAL in the competitive landscape, we plot the graph of operating income versus total cost for the U.S. airlines (Figure 24). Clearly, Delta, United, and AAL were similar in size (total revenue). Delta and United had a much higher operating income than did AAL, with lower costs. Southwest (LUV) was smaller in size but above the regression line, indicating that

Figure 24. (Color online) Competition positioning of U.S. and Chinese airlines: operating income vs. total cost in 2019.



Source. Zhao [15, slide 5]; developed by SCDATA.ai. See https://SCDATA.ai.

Figure 25. (Color online) Competition positioning of U.S. and China airlines: return on assets vs. liability asset ratio in 2019.



Source. Zhao [15, slide 11]; developed by SCDATA.ai. See https://SCDATA.ai.

it was quite profitable compared with other airlines. Alaska Airlines and other U.S. airlines were small and clearly not in the same league as AAL. By comparison, the airlines in China (dots in red) had a much lower profitability than the U.S. airlines.

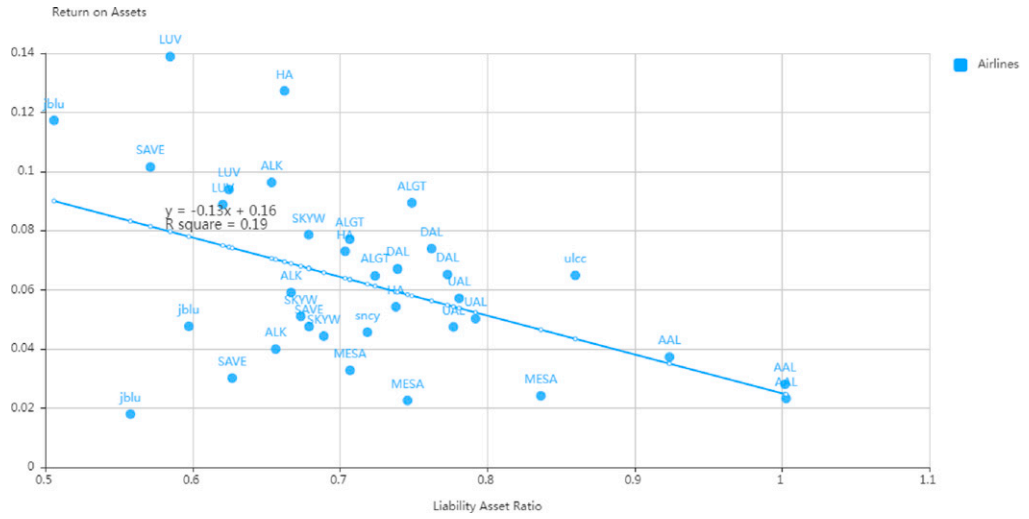
Let us now position AAL on the return versus risk map of the U.S. airlines industry, which shows two important factors—return on assets (ROA) and the liability asset ratio—simultaneously. Figure 25 provides interesting insights: First, AAL's liability asset ratio is above 1, which means that the company's liability is greater than its assets in 2019. Second, AAL had the lowest ROA among all U.S. airlines, even below that of Alaska Airlines. Delta and United had about the same liability asset ratio, but Delta's ROA was much higher. Finally, LUV had the least liability asset ratio but the highest ROA, explaining its outstanding performance in the stock market. In summary, AAL was the worst on both ROA and liability asset ratio, and Southwest was the best, whereas Delta and United were in between. By comparison, the Chinese airlines were lower in their liability asset ratio but also lower on ROA than the U.S. companies.

The value driver analysis on U.S. airlines in 2017–2019 finds a quite strong negative correlation between the ROA and liability asset ratio. That is, a higher liability asset ratio may lead to a lower ROA for the airlines (Figure 26).

A breakdown analysis of the revenue and assets can analyze and compare their components for the objective of diagnosing the causes for problems. For example, if the industry's average SG&A cost is 10% of the revenue, but one company has 15%, then the company must have spent too much on SG&A. For the U.S. airlines, we first break down the revenue and find that COGS and other costs were the biggest components from the industry average (see Figure 3). We also see that AAL's COGS as a percentage of its revenue was 2% higher than the industry average. But AAL's biggest difference from its peers was its high other costs (~ 14% of the revenue), whereas the industry average was 11%. Thus, AAL's net income was 3.7%, which is much lower than the industry average of 7.6%. By comparison, Delta had a similar COGS but much lower other costs and so enjoyed a ~ 10% net margin. The advantage of Southwest was on COGS, which was 2% less than the industry average, and a minimum SG&A. So even with higher other costs (still lower than AAL), Southwest also enjoyed a 10% net margin.

The breakdown of total assets allows us to gain more insights into their differences (Figure 27). Here, I just want to point out two interesting facts: First, AAL had almost zero cash, but

Figure 26. (Color online) Value driver analysis between return on assets and liability asset ratio, U.S. airlines in 2017–2019.



Source. Zhao [17, slide 17]; developed by SCDATA.ai. See https://SCDATA.ai.

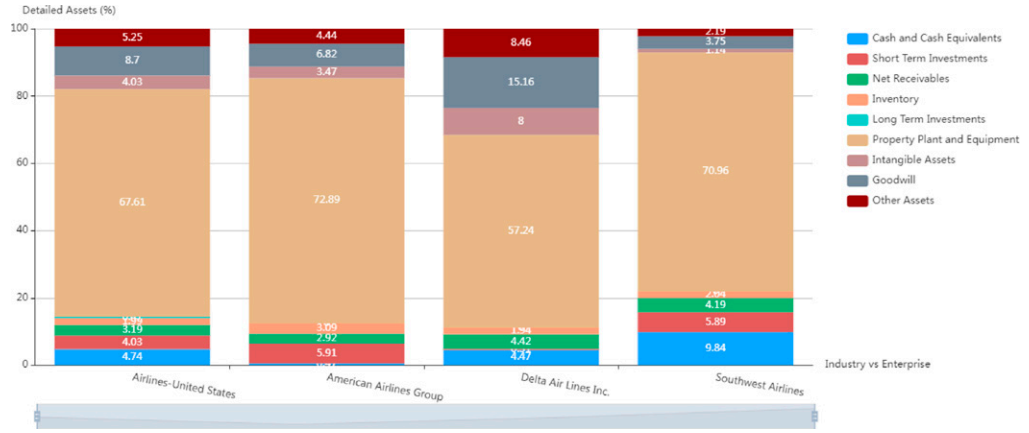
Southwest had lots of cash. Second, Delta was much lighter on property, plant, and equipment than were other airlines, explaining the reason behind its unusually small other costs (which include interests, for example).

In summary, AAL may look like a lion, but actually, it is a small cat. In other words, AAL is the largest airline in size but weakest in profitability, growth, and financial health. Let's be fair: the airline industry is very competitive, and almost everyone's profit margin is shrinking. However, AAL has clearly been the worst performer in recent years, and the stock prices told the truth. To turn the company and stock price around, AAL needs to reduce liabilities (e.g., other costs) and improve its utilization and return on assets.

6. Conclusion

Data-driven descriptive and diagnostic analytics is largely ignored in operations and supply chain management teaching. Its value and challenge, especially in the area of problem

Figure 27. (Color online) Asset breakdown of the U.S. airlines in 2019.



Source. Zhao [17, slide 27]; developed by SCDATA.ai. See https://SCDATA.ai.

definition and discovery, are overlooked among operations and supply chain management academicians (Davis [4]) but widely recognized in managerial accounting and financial management curricula. The critical features that make supply chain analytics–based problem discovery different is the focus on operations and supply chain–related KPIs and applications, such as inventory, sourcing, and competitive benchmarking with an operational perspective.

Companies have spent tons of money each year hiring consultants to solve problems that they are trained to solve, but they may be failing to identify the right problems in the first place. This is true because one often interprets the world out of his or her prior beliefs (e.g., Bayesian prior) and fits the data into an existing toolbox instead of seeing the world (or data) as it is. But if you can jump out of the box and see the data as they are, then, as Steve Jobs would say, you can define the problem correctly, which means you almost have the solution.

Acknowledgments

The author is indebted to the volume editors Dr. Mabel Chou and Dr. Douglas Shier for their encouragement and support and two anonymous reviewers for their constructive comments and helpful suggestions that helped the author significantly improve this tutorial.

Endnote

[1]Other costs are the costs of a company that are not a part of the cost of goods sold, research and development expenses, tax payments, and sales, general and administrative cost. They include interests and government subsidies among others.

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