Chapter 10
Build-to-Order Meets Global Sourcing: Planning Challenge for the Auto Industry

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10.1 Introduction

Auto manufacturers today face many challenges: The industry is plagued with excess capacity that drives down prices, international competitors are seizing share at both ends of the market and consumers are well informed about options and prices. All these factors combine to heighten competitive pressures, squeeze margins, and leave manufacturers struggling to increase revenues and market share.

A nearly universal strategy in the ensuing battle for market share and survival has been to increase product offerings in terms of both models and options. Long gone are the days when a black Model T, or a black Hongqi for that matter, was the only choice. Today's increased product variety, however, complicates operations and confounds demand forecasting. Correcting the inevitable forecast errors with discounts and rebates not only erodes manufacturers' margins, but also damages brand image. Consumers now expect to get less than they wanted and to pay less for it.

As competitive pressures increase, companies look overseas for new markets and low cost suppliers, elbowing their way into high-growth developing markets with new international assembly operations and sourcing more and more components from distant low-cost suppliers.

Offshore suppliers and international assembly operations bring long and variable lead times that complicate demand forecasting, production planning and supply. Under pressure to keep inventories lean, manufacturers often find needed supplies are still at sea and end up expediting parts to keep production lines running. It is no wonder that Womack and Jones (1996) said, "Oceans and lean production are not compatible." Incompatible or not, both lean production and transoceanic supply are here to stay and manufacturers are left with the daunting task of managing this "inherent incompatibility."

We address this challenge from the perspective of a global build-to-order (BTO) auto manufacturer. BTO is an attractive strategy for dealing with increased

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product variety and reducing finished goods inventories, defined as "the practice of building customized or standard products as they are ordered and shipping them directly to customers, instead of building-to-forecast and shipping from inventory" (Anderson 2004). Today, many auto manufacturers, such as BMW, Toyota Scion, Renault, Mercedes-Benz, use BTO to some extent.

As BTO meets global sourcing, we observe that some familiar tools for managing domestic supply can improve international supply, but have yet to be effectively exploited. In other cases, traditional approaches come up short or are fatally flawed. For example, we find that increasing the frequency of shipments, a fundamental strategy of lean production long employed in improving local supply, also reduces inventory and risk for international supply. However, improving the accuracy and detail of demand signals, while still important, loses much of its impact in the face of long and variable lead times. Proprietary studies we carried out for a European auto manufacturer show that as things stand in the global auto industry even the Herculean feat of doubling forecast accuracy would reduce inventory and expediting costs by less than 10%. In fact, our analysis strongly suggests that *reducing* the level of demand detail communicated to distant suppliers can simultaneously improve their quality of service and reduce their cost in providing it. Chen et al. (2000) reach a similar conclusion and observe that updating demand information periodically results in a higher variance in the orders placed.

We reach this counterintuitive conclusion through a new shipping policy, called "Ship-to-Average," which ships the same quantity (based on the long-term average forecast) each time and adjusts this quantity only when inventory drifts out of prescribed ranges or the forecasted average rate of demand changes. Ship-to-Average is much easier to implement than currently accepted "Ship-to-Forecast" policies that slavishly follow detailed demand signals and, in the process, unnecessarily amplify the bullwhip effect, creating wild swings in capacity requirements on both the suppliers and the transportation providers.

In Sect. 10.2, we elaborate the challenges that auto manufacturers face today. We focus on the resulting product proliferation as the manufacturers target smaller and smaller segments of the market in an attempt to maintain and grow market share. We discuss the shortcomings of traditional push systems when faced with a wide variety of product offerings and observe how BTO helps manage this variety. However, BTO simply shifts the challenge from forecasting finished goods demand to forecasting individual component demands. We look at how variability in part usage and the trend toward global outsourcing in the auto industry affect forecast accuracy and the value of improving it. Finally in Sect. 10.3, we propose first step strategies for managing the inherent incompatibilities in automotive supply chains.

10.2 Refining the Challenge Definition

Auto manufacturing is a capital-intensive industry. Developing a new vehicle can cost $1 billion and a new assembly plant to produce the vehicle typically costs another $1–3 billion. To be price competitive, manufacturers must spread these capital investments over large volumes, but vehicle lifecycles are shortening and the number of different models on the market is growing.

Manufacturers often look for new sales volume in overseas markets. North American manufacturers, such as Ford and GM, for example, have long had operations in Europe and are rapidly ramping up operations in Asia, especially in China and India. European manufacturers are also highly involved in foreign operations. Manufacturers from Japan and Korea have made deep inroads in the USA and are taking a second run at Europe; Chinese manufacturers are poised to follow.

Globalization has been both a blessing and a curse. While it has opened up new markets, it has also brought new competitors. The big three in North America (GM, Ford, and the Chrysler unit of DaimlerChrysler) have lost more than 20% of their share in the USA, primarily to Japanese and Korean competitors, in the past two decades. In 1965, the Big Three accounted for 95% of all vehicles sold in North America. Today, that figure has fallen to only 58.5% and will continue to decline. In fact, some industry analysts forecast the Big Three's market share will fall to 50% by 2008. Japanese brands alone now account for 30.6% and the more recent entrants from Korea already account for 4.1% (Office of Aerospace and Automotive Industries (2005)). Now, Chinese manufacturers are poised to enter the market with lower costs and prices as Chinese auto assembly workers typically work for as little as $2/h including wages and benefits, compared to $22/h in Korea and nearly $60/h in the USA (Bremner and Kerwin (2005)). For example, the Chinese manufacturer, Chery, is aiming at the premium end of the market but with prices 30% below those of its rivals (Dyer and Mackintosh (2005)).

EU manufacturers face a similar threat. While initial efforts by Japanese manufacturers in Europe were not as successful as in the USA, Japanese brands are the largest external players in European markets today. In the passenger car market, Japanese and Korean brands' market share climbed from 11% to more than 17% between 1990 and 2005 (ACEA (2006)). American manufacturers also compete in the European markets, but mostly through their European branches and hence brands.

As auto manufacturers increase their global presence by opening new plants in new or emerging markets, they contribute to the significant overcapacity already present in the industry. Globally, it is estimated that in 2005, the industry had enough idle capacity to produce an additional 18 million cars (PWC (2006)) – equivalent to almost 33 times the annual production of the largest assembly plant in North America (the Smyrna, TN Nissan plant makes around 550,000 vehicles per year). There is clearly a mismatch between capacity and demand.

10.2.1 Product Proliferation

In the race for market share, almost every manufacturer has pursued smaller and smaller segments of the market with more and more models and options. Even a mass-market auto manufacturer such as Ford Motor Company offers a dizzying array of products. Consumers can choose from among 23 models of Ford vehicles and a variety of options for any given model, so there are several million possible configurations to choose from. For example, among the 5 different Ford Escape models (XLS manual, XLS automatic, XLT automatic, XLT sport, and limited automatic) consumers can choose:

- Either front-wheel drive or four-wheel drive.
- A 2.3L or 3.0L engine.
- 4-speed or 5-speed transmission.
- From nine exterior color options, three interior colors, four wheel options, two choices of tires, four options of electronics, and four options of seats.
- Various combinations of five special option packages representing 32 different possibilities.
- Various combinations of four different upgrades representing a further 16 options.

All told, these options lead to something like 70 million different configurations of the Ford Escape.

As an extreme example, BMW offers its customers an essentially infinite number of products: 10^{32} different vehicle configurations by its own estimates. Just the 7-Series with more than 350 model variants, 175 interior trims, 500 options, and 90 standard colors, represents 10^{17} possible configurations. That is nearly 17 million different configurations for each man, woman, and child on the planet. To put these astronomical figures into context, consider this: the Spartanburg, SC plant produced a quarter million Z3s (the predecessor of Z4) before it produced two that were identical.

BMW is so convinced that this huge variety of options drives additional sales that they even retain options with very low (lower than 1%) uptake rates. The success of this strategy is evidenced by the fact that BMW sales surpassed Mercedes in the years after the introduction of the "Customer-Oriented Sales and Production Process" (KOVP), BMW's BTO system. Similar strategies have been widely adopted across the industry, though the success of certain Japanese brands, such as Lexus, one of the BMW's strongest competitors, serves as a strong counterpoint to the argument.

10.2.2 From "Push" to BTO

The traditional "push" systems in which manufacturers build to forecast and meet customer demand from available finished goods inventory are struggling to keep up with the new challenges of product proliferation. Can Ford Motor Company, for example, really expect to accurately forecast demands for each of the 70 million variants of the Escape? The company only sold about 183,000 Escapes in 2004. In such a crowded market, even forecasting total annual sales for the model is a challenge.

When forecasts are wrong, manufacturers are forced to offer significant incentives to sell remaining inventories. In the USA alone, automakers are estimated to have spent $60 billion in rebates in 2004[1], with more than 90% of all cars sold having some form of incentive. The Big Three spent more than $4,500 per vehicle on incentives that year and even popular Japanese brands that long shunned the practice succumbed to the inevitable pressure: "Toyota's incentives in all forms were up 31.6% in 2004, reaching a level of over $3,100 per vehicle. Nissan's incentives were up 26.0% to almost $2,000 a vehicle and Honda increased incentives by 79.5% to almost $2,000 a vehicle" (Office of Aerospace and Automotive Industries (2005)). Despite these big incentives, however, no one is really satisfied with the end result. Manufacturers give up margin and consumers have to settle for what is available, not necessarily what they really wanted. It is no wonder so many manufacturers are moving toward BTO systems that convert orders to products without holding any finished goods inventory.

For BTO strategies to be successful, it is essential to have short order-to-delivery lead times. Typical lead times for a custom-built vehicle range from 6 weeks to 10 weeks, while customers expect their vehicles within 2–3 weeks. As a result, only a minority of vehicles in the market are custom built, and manufacturers end up holding up to 100 days of sales in the market place (Miemczyk and Holweg (2004)). Especially, in the USA, customers rely mainly (more than 90% of sales (Miemczyk and Holweg (2004))) on the build-to-stock model and expect vehicles (close to what they really wanted) in 2 or 3 weeks (i.e., the time required to transfer it to their dealer). In contrast, European customers rely more heavily on BTO and accept lead times of several months, but expect exactly what they ordered.

To get consumers and dealers to accept lead times of 2–3 months, some manufacturers allow them to change their choices within this period. For example, BMW's Customer-Oriented Sales and Production Process (KOVP) allows a customer to change his or her order up to 6 days before the vehicle is produced. In fact, a customer may change major specifications such as the engine, transmission, color, or optional equipment within days before the vehicle is assembled, without affecting the agreed upon delivery date. And customers exercise this flexibility: BMW responds to more than 120,000 change requests every month. This flexibility also allows BMW dealers to meet individual customer requirements more quickly. Typically, dealers place an order for a basic vehicle in advance, and make changes to that order as customer demand takes shape. In many cases, the dealer can offer a customer exactly the vehicle he or she wants within a 2 or 3-week window.

A side benefit of this flexibility is that, more often than not, customers tend to upgrade to more expensive options such as navigation systems, xenon lights, and electronically adjustable comfort seats, etc., as the delivery date approaches. Thus, by allowing its customers flexibility, BMW is not only able to get those orders earlier – generally months in advance – but it also enjoys enhanced revenues from the resulting upgrades.

[1] The US Bureau of Economic Analysis estimates "Final sales of motor vehicles to domestic purchasers" at $518 billion in 2004.

10.2.3 Capacity and Variability

In the auto industry production, capacity represents a major capital expense and production labor is skilled, highly organized, and expensive. Consequently, companies rely on a variety of strategies to smooth demand. In fact, an assembly plant's daily production is set to a takt time, e.g., a vehicle every 50 s. Changes in production are accomplished by speeding or slowing the takt time, adding or reducing shifts or shutting down the facility for a period of time during the year. The latter two adjustments are very crude indeed and are planned far in advance. Reductions to the takt time translate immediately into increases in the labor cost per vehicle produced and so are again only made reluctantly and as part of a broader plan to manage capacity.

Thus, over significant time periods the production rate in terms of vehicles produced per day, per shift, and even per hour is quite constant. Significant deviations from this rate are rare and usually the result of quality or supply problems.

Although an assembly plant typically produces vehicles at a remarkably constant rate, the composition of these vehicles can vary widely in terms of both the options they require or – as manufacturers move to more flexible lines, in terms of the mix of models produced. For example Hyundai's plant in Montgomery, AL builds Sonata sedans and Santa Fe SUVs on the same line. That plant is designed to accommodate as many as four different models simultaneously. Similarly, Honda's plant in East Liberty, OH produces cars and light trucks on the same assembly line, while Ford's flexible plant in Chicago is capable of building eight models off two platforms and the Dearborn plant nine vehicles off three platforms. This flexibility helps spread capital costs and risk.

As a consequence, even though automobile assembly plants make the same number of vehicles every day, demand for the components that go into those vehicles is increasingly unpredictable. Apparently, modifications in plant design are ahead of modifications in vehicle design: while manufacturers are driving down the number of "platforms" progress in achieving commonality in parts across models has been slow. In fact, it is not unusual in the industry to see usage of a part vary by more than 70% from one day to the next. BTO, which was intended to free manufacturers from the tyranny of poor forecasts, simply shifts the problem from forecasting finished vehicle demands to forecasting demands for components.

10.2.4 Global Sourcing

A major trend in the auto industry is globalization. Auto manufacturers not only produce vehicles around the world, but they also increasingly rely on low-cost overseas suppliers to do it. For example, U.S. manufacturers import parts from Mexico, Brazil, and now China and India. Sourcing from offshore suppliers is not limited to the original equipment manufacturers. This trend is visible even among first tier suppliers such as Cummins International (engine parts), Delphi and Visteon (www.ibef.in/industry/autocomponents.aspx). As a result, in the past

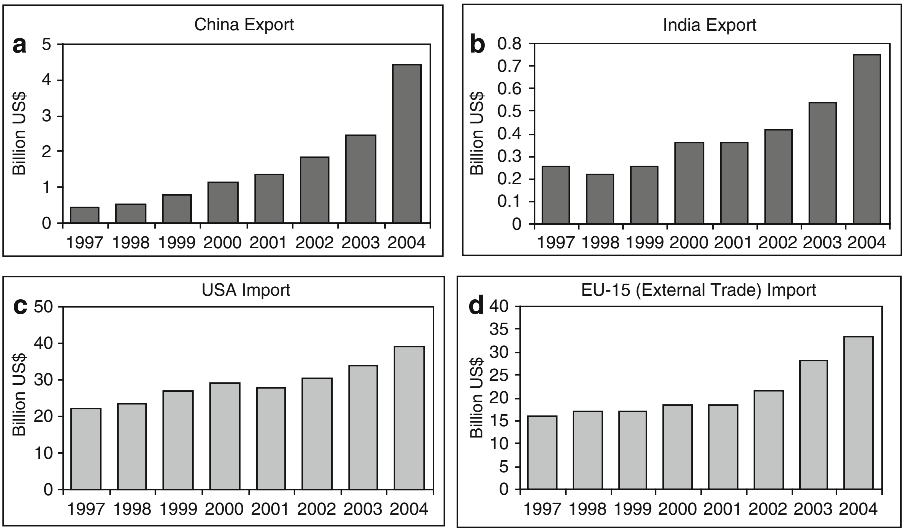

Fig. 10.1 Import and Export of auto components. Source: OECD ITCS – International Trade By Commodity Statistics, Rev. 3 (**a**)–(**c**), India Department of Commerce (**d**)

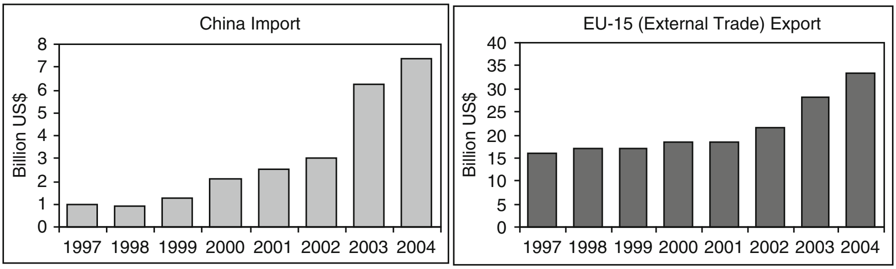

Fig. 10.2 European auto components exports increase with international operations. Source: OECD ITCS – International Trade By Commodity Statistics, Rev. 3

decade, China's exports of auto components have increased more than eightfold and U.S. and European imports of auto components have doubled (See Fig. 10.1).

However, many companies supply international operations from domestic markets for reasons of quality, economics, and sometimes out of social obligations. EU manufacturers, for example BMW, Volvo, Daimler Chrysler, and PSA, supply operations in USA, Brazil and increasingly China with parts from European suppliers. The decision to use domestic markets to supply international operations is based on several factors. Having already invested in the tooling in Europe, the volumes in this hemisphere may not support replicating those costs. Furthermore, the quest for quality or desires to protect proprietary processes sometimes prevents the use of untried new overseas suppliers. Likewise, existing relationships with suppliers and social responsibility issues all play a part in the decision to supply international operations from home markets. Hence, imports of auto components into countries such as China are on the increase along with the export volumes of EU countries supplying them (See Fig. 10.2).

10.3 Rethinking Familiar Tools and New Models

The wide variety of product offerings and commitments to rapid order fulfillment and near-zero inventories create demands for individual parts that vary wildly from day to day. Combined with global sourcing – hence, long and variable lead times – supplying individual parts becomes a very complex process, often forcing manufacturers to expedite parts to keep production lines running. Managing this "inherent incompatibility" between lean production and transoceanic supply is a daunting task for manufacturers.

In this section, we observe that increasing the frequency of shipments – a fundamental strategy of lean production long employed in improving local supply – also reduces inventory and risk for international supply. In other cases, traditional approaches come up short or are fatally flawed. For example, improving the accuracy and detail of demand signals, while still important, loses much of its impact in the face of long and variable lead times. Finally, we look at a new shipping strategy, Ship-to-Average, which relies less on the inevitably erroneous forecasts that accompany international supply and instead focuses on longer-term trends in demand. In fact, our analysis strongly suggests that reducing the level of demand detail communicated to distant suppliers can simultaneously improve their quality of service and reduce their cost in providing it.

10.3.1 Increasing Frequency

Auto manufacturers have long recognized the value of frequent deliveries from local suppliers: more frequent shipments mean smaller shipments and smaller shipments mean less inventory. More frequent shipments also mean less time between shipments and so less risk of interrupted supply – if something goes wrong with one delivery, another is not far behind.

Frequent deliveries are a cornerstone of lean production that Toyota has exploited to the fullest. The carmaker brings parts into its plants more than once an hour. Can these same ideas improve international supply? Hourly shipments may not be feasible, but increasing the frequency of shipments and reducing the risk of expediting is still a viable approach. Today, most manufacturers make what amounts to weekly shipments for internationally sourced parts. This means that on average they must carry not only a large safety stock to protect against delays in delivery or sudden increases in demand, but also half a week's supply as cycle stock.

Proprietary studies we carried out for a European auto manufacturer provide valuable insights about the impact of shipping frequency (as well as some other tools and policies mentioned in following sections). In these studies, using the characteristics of the manufacturer's original demand and rolling forecast data, we created an extensive test bed of realistic data. We similarly analyzed the statistical properties of shipping delays and lead times. We tested each of the different approaches via simulation using the resulting test bed of data on forecasts, demand and shipping delays.

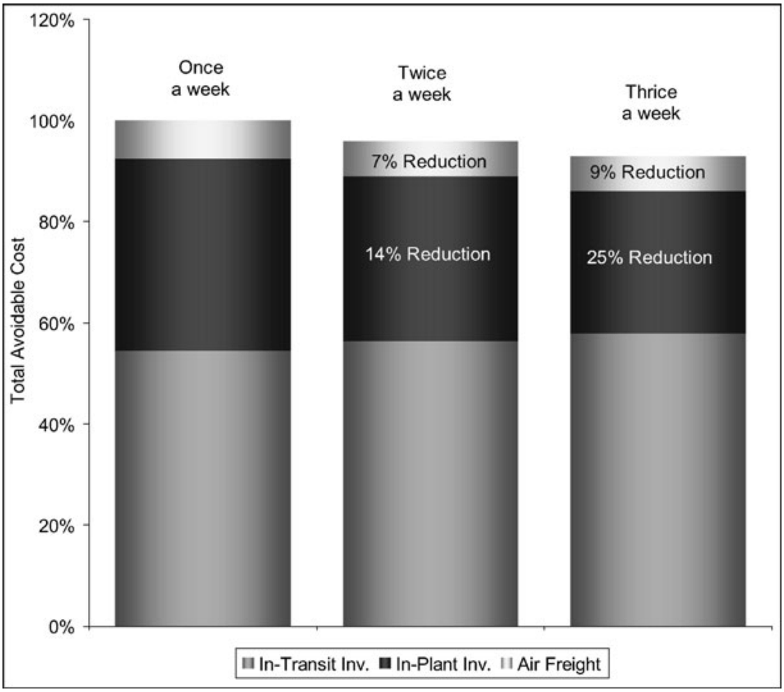

Fig. 10.3 Cost savings through increased frequency of shipments

The results of our analysis, depicted in Fig. 10.3, suggest that increasing the frequency of international shipments can offer significant savings both in inventory and in expediting costs. Here, we ignore the transportation costs, other than expediting, since over all the same amount of parts have to be shipped, and ocean shipping costs are generally incurred per container shipped. Increasing the frequency of shipments reduces the number of containers on each vessel, but does not increase the number of containers shipped each year. Our analyses, based on the characteristics of a European manufacturer supplying assembly operations in the USA, show that doubling the frequency of shipments from once-per-week to twice-per-week simultaneously reduce in-plant inventories by 14% and expediting costs by 7%. Moving to three shipments per week reduces in-plant inventories by 25% and expediting costs by 9%.

Increasing frequency, by itself, has no effect on in-transit inventories, but since the total costs decrease, in-transit inventories as a share of total avoidable costs in Fig. 10.3 increases slightly as we increase the frequency of shipments.

The ocean container lines' sailing schedules force manufacturers that source parts from overseas to work under a periodic review system since, regardless of when orders are placed, they can only be delivered when vessels are scheduled to arrive. Scarf (1960) established the optimality in this setting of (s, S) policies, which at each time period either place an order to bring the inventory level up to level S or, if the order quantity is too small and inventory levels are already greater than s, place no order at all. As a consequence, although the time between orders is relatively constant, the order quantities can vary widely.

The risk of stocking out in an order cycle depends on the variability of demand in a period determined by both the time between orders and the lead time (Silver et al. (1998)). Increasing the frequency of orders reduces the time between orders and so reduces the risk of stocking out in an order cycle (assuming we hold safety stocks constant). However, increasing the frequency of orders increases the number of order cycles in a year and so means we face this reduced risk of stocking out more often. The overall impact of increased frequency on safety stock depends on the balance between these two factors. In our experience, the benefits of reducing the risk of a stock out in each cycle outweigh the costs of additional cycles even for frequencies beyond those achievable with ocean shipping schedules.

Increasing frequency only reduces inventory and expediting costs if the shipments are mixed. Simply increasing the number of vessels used has little or no impact beyond spreading the risks if individual components are still shipped once per week. In other words, shipping containers on three different vessels each week is little different from shipping them all on a single vessel if each part number is only on one vessel. To realize the savings, each component has to ride on each vessel and achieving this may require more packaging flexibility and increase handling costs. In our study, the inventory and expediting savings more than compensate for any extra handling.

Increasing the frequency of shipments from local suppliers typically increases transportation costs because it reduces capacity utilization of transportation or requires a larger number of smaller vehicles to make the deliveries. This is not generally the case for international shipments, or at least the impact on transportation costs is less pronounced. This is because, with the exception of a few high-volume suppliers that ship direct, most internationally sourced components are already consolidated for international packaging. Thus, while increasing the frequency of these shipments will generally increase transportation costs between the supplier and the consolidation center, it has little effect on the international transportation costs. Ocean shipping costs are generally incurred per container shipped, so shipping 100 containers on three different vessels costs essentially the same as sending 300 containers on a single vessel each week.

Unfortunately, sailing schedules make it difficult for companies to increase international shipment frequencies. The carriers all try to set sail at the end of the week, so their vessels are not idled at port over the weekend. The impact: 90% of the fastest 30% of services from Hamburg to Charleston and 80% of the fastest 30% of services between Hong Kong and Long Beach are scheduled to arrive between Friday and Sunday. To achieve higher frequencies, shippers are forced to use services out of and into alternative ports. While this certainly complicates the logistics, it has the added benefit of reducing the risks of disruptions in the case of a port strike or a hurricane.

10.3.2 Improving Forecasts

As manufacturers struggle to manage the "inherent incompatibility" between lean inventories and long lead times, their first reaction is typically directed at improving the accuracy of demand forecast through investments in information technology. They develop advanced forecasting models in order to capture the nature of demand and invest in new sales and operations planning software to get a better handle on their supply chain. While in general there is a consensus that improved forecast accuracy has positive impact, there is no clear single method to achieve it, or even identify the extent to which it can be achieved. In any case, everyone agrees it is impossible to eliminate forecast errors altogether.

While forecast accuracy is important and efforts to improve it should not be abandoned, this avenue offers little prospect for resolving a significant portion of the "inherent incompatibility." Demand variability for option parts is an inherent component of the flexibility manufacturers must allow consumers (and dealers) in order to get orders far enough in advance. Hence, a certain amount of forecast inaccuracy is inherent in BTO. There are four ways to reduce the demand variability engendering forecast errors:

1. *Reduce the number of options*: Low volume parts are the most difficult to forecast and managing them takes the same effort if not more than high volume parts. Eliminating the least popular options improves forecast accuracy for the more popular ones and reduces the complexity of managing supply.
2. *Increase the "frozen horizon"*: Freezing orders earlier fixes the production schedule further in advance, allowing the manufacturers to work with shorter forecast horizon i.e. closer to the actual demand.
3. *Source from local suppliers*: Reducing lead times significantly improves forecast accuracy.
4. *Exploit postponement strategies*: By delaying the point of product differentiation as close as possible to actual order information and waiting until actual order signals are received to complete the products, postponement offers manufacturers the flexibility they need to efficiently produce customized products.

Toyota effectively exploits postponement to provide U.S. customers with almost unlimited customization of the Scion even though that model is built in Japan. Scion customers in the USA can chose from over 40 different options, leading to 2^{40} different versions of the vehicle – more than 3,000 different versions for each person in the USA. However, the vehicles produced in Japan are standardized; distinguished only by transmission (automatic or manual) and color (there are 6 choices). These standardized vehicles are customized to order in the U.SA and delivered within 5–7 days.

Toyota's postponement strategy for the Scion would be difficult to implement for higher end vehicles with fewer standard features and more complicated option offerings that can only be added during production, but that does not mean postponement is not a viable strategy for complex subassemblies such as wiring harnesses and cockpits.

Unfortunately, none of these options is particularly attractive or available to manufacturers. Furthermore, with the exception of the Scion, these "solutions" are contrary to the trends in the industry.

Our studies strongly suggest that even if we could improve forecast accuracy significantly, it would have limited impact. In fact, our studies indicate that the Herculean accomplishment of halving forecast errors would only reduce inventory and expediting costs by less than 10%.

In our studies, using a history of orders and rolling forecasts similar to those of a European auto manufacturer, we artificially improved the forecast accuracy and evaluated the impact on inventory and expediting.

Figure 10.4 illustrates that even significant improvements in forecast accuracy yield only relatively small improvements in inventory and expediting costs. In fact, our studies indicated that cutting forecast errors in half – from 75% to about 37% – reduced inventory and expediting costs by less than 10%. The reason: Poor forecasts are the scapegoat for all the excess inventories, stock outs, and premium freight charges. But they simply do not deserve the blame, at least not by themselves. Inaccurate forecasting is just one factor contributing to the problem. The other culprit is lead time variability. Accurate demand forecasts can tell you how much you will need, but if lead times are unreliable you are still left with the question of when to ship, so it arrives when you need it.

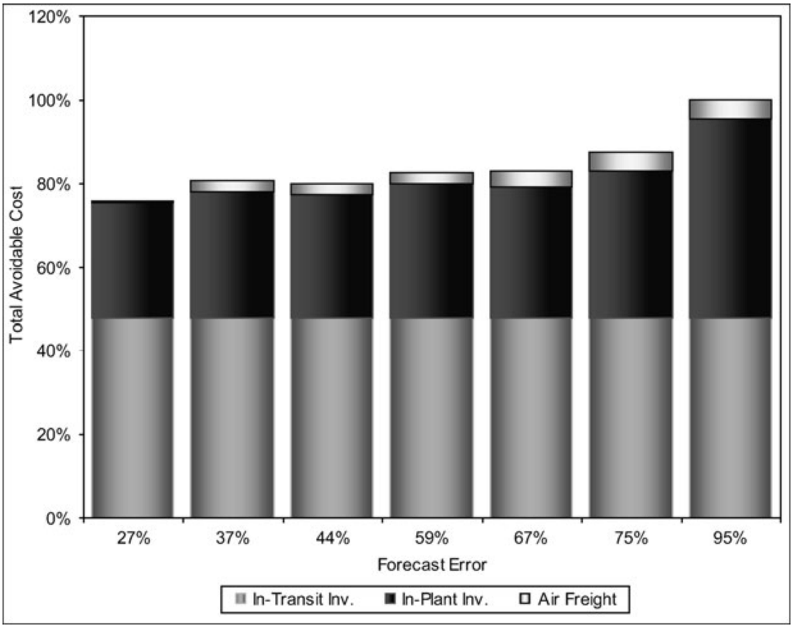

Fig. 10.4 Inventory and expediting costs at different forecast error levels

The mean and variance of lead time demand when lead times are stochastic are modeled by the following well-known expressions, where μ_L and σ_L are the mean and standard deviation of lead time, respectively, and μ_D and σ_D are the mean and standard deviation of demand over a single time period.

$$\mu(\text{lead time demand}) = \mu_D \mu_L$$
$$\sigma^2(\text{lead time demand}) = \mu_L \sigma_D^2 + \mu_D^2 \sigma_L^2.$$

Hence, it is clear that both the mean and the variance of lead time play an important part in managing lead time demand. Increased variability in lead times increases variability in lead time demand, making it more challenging to manage supply. When lead times are long (as in the case with manufacturers working with transoceanic suppliers), the risks of stocking out from one order cycle to the next are dependent since the intervals in question overlap, and thus, more challenging to quantify; one motivation for our reliance on simulation studies.

Lead time variability has been on the rise, driven by increasingly violent and unpredictable weather (the 2005 Atlantic hurricane season, with 28 nameable storms is the most active season on record, surpassing the 1933 season's 21 (National Oceanic & Atmospheric Administration (2005))) and the general strain on the global transportation system.

North America has a growing port capacity problem, and the resulting congestion is affecting global supply chains negatively. Over the last 20 years, container volumes in North American ports have grown at an average annual rate of 7%, but port capacity has not kept pace with volume growth (Maloni and Jackson (2005)). A study by the National Chamber Foundation of the U.S. Chamber of Commerce pointed out that most major North American ports are already operating at or near full capacity and will have significant capacity deficits by 2010 (National Chamber Foundation of the U.S. Chamber of Commerce (2003)). Port congestion leads to unpredictable delays, causing manufacturers to increase inventory levels and adjust supply networks to minimize the risk of stock outs and shutdowns. A 2004 survey by *Logistics Management* magazine revealed that respondents were experiencing average delivery delays of 6.5 days. Approximately 43% of the respondents reported 8 or more days of delay, while 53% reported delays between 3 and 7 days (Levans (2005)- See Fig. 10.5). Even if manufacturers' ability to predict what they need improves, their ability to predict when it will get there is declining.

The principal impact of improved forecasts is to reduce the need for expedited shipments. The auto industry with its heavier, lower value parts, typically reserves airfreight for emergencies. Hence, increasing forecast accuracy principally reduces the already small airfreight costs and so has a relatively small impact overall. A parallel study with a telecommunications equipment manufacturer, however, indicated that improved forecast accuracy can have significant impact on companies that rely heavily on airfreight and expedited shipments to meet customer orders.

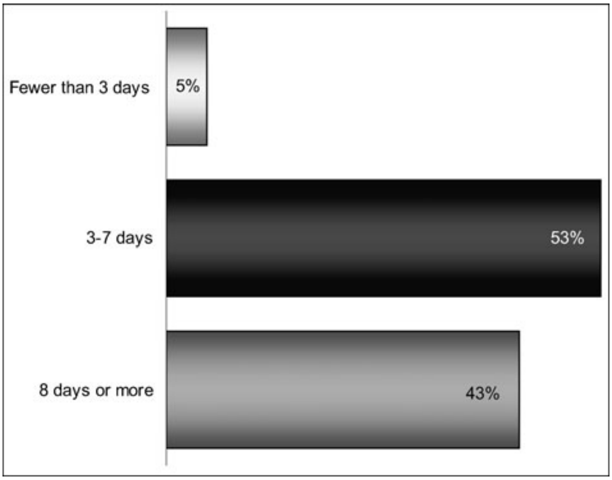

Fig. 10.5 "How much delay are you experiencing in delivering your products due to West Coast backup?" (Levans (2005))

10.3.3 Ship to Average

Traditional methods for managing supply rely on detailed forecasts. Each order quantity is based on forecasted demand over the period the order is intended to cover: a week's forecasted production for weekly shipments, a few days' forecasted production with more frequent shipments. These methods suffer from two obvious difficulties: First, as we have seen, actual production quantities over periods as short as a week or a few days vary widely; second, forecasts of these quantities are remarkably inaccurate. The result: Traditional methods magnify the bullwhip effect and send international suppliers and logistics service providers on a wild goose chase after phantom peaks in demand.

We propose a simpler, and it turns out, more effective strategy for managing supply, which we call Ship-to-Average. The idea is to keep order quantities constant, adjusting them only when inventory drifts out of prescribed ranges or the average rate of demand changes. Ship-to-Average offers several advantages: First, since changes in the order quantity are the exception rather than the rule, Ship-to-Average policies reduce the effort involved in managing supplies. Second, since order quantities are consistent and reliable, suppliers and service providers can more efficiently plan production and manage labor requirements. Finally, the manufacturer can count on more consistent and reliable shipment quantities and no longer needs complicated calculations to determine whether it is necessary to expedite parts.

Ship-to-Average policies *do* use forecasts to calculate fixed order quantities, but ignore the details in these forecasts and instead focus on longer-term trends. Figure 10.6 shows the relationship between forecast errors and the period of demand forecasted in the case of a European manufacturer forecasting demands

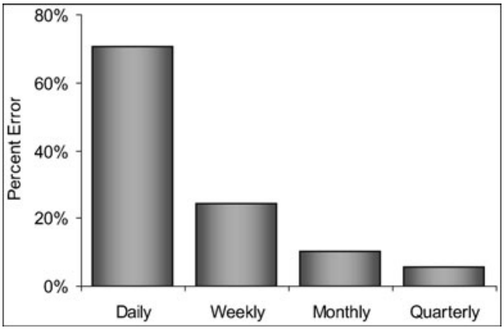

Fig. 10.6 Forecast errors covering different periods

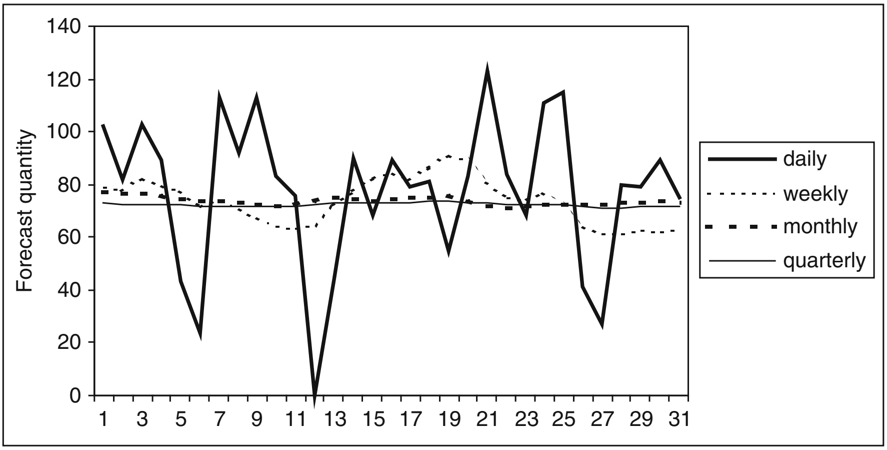

Fig. 10.7 Forecasts over different time periods

for an option-driven component at a North American plant 30 days in advance. Figure 10.7 compares the stability of the forecasts averaged over different time periods. As expected, forecast accuracy and stability improve significantly with the length of the period forecasted. While daily forecasts are inaccurate and swing wildly, weekly, monthly and quarterly forecasts are increasingly accurate and stable. Ship-to-Average policies ship to the more stable and accurate average of forecasts covering longer periods.

Although there is no theoretical proof that Ship-to-Average is a best strategy in general, Ormeci et al. (2008) proved that, in the case of zero lead times, policies of this form are optimal. Initial studies based on the characteristics of a European auto manufacturer suggest that Ship-to-Average policies are at least as effective as the current Ship-to-Forecast strategies in terms of average inventory and expediting costs. In many cases, Ship-to-Average simultaneously reduces total avoidable cost, expediting costs and the variability in order quantities, and the reductions in expediting costs and order variability are significant (60% and higher reductions for expediting; 50% and higher reductions for order variability) with no increase in total avoidable costs. So far, we have always been able to identify a Ship-to-Average policy that significantly improves order stability without increasing total avoidable cost when compared to the best Ship-to-Forecast policy.

Ship-to-Average policies produce significantly more stable order patterns, which simplify the suppliers' task of managing labor and capacity. Consider the example of a large, high-value option-driven part shipped from Europe to a North American plant. Adopting the standard that a change of more than 10% in successive order quantities creates planning and scheduling challenges for the supplier, we found that while the best Ship-to-Forecast policy exceeded this limit more than 60% of the time, our Ship-to-Average policy exceeded it less than 15% of the time with the same total avoidable cost. That additional constancy and predictability helps suppliers better manage their resources and realize savings that should eventually be reflected in piece prices.

10.4 Conclusions

One of the most important challenges facing BTO auto manufacturers is the wide variety of product offerings, commitments to rapid order fulfillment and near-zero inventories creating demand for individual parts that vary wildly from day to day, while supplying these parts globally with long and variable lead times.

Increasing frequency is a simple and efficient tool to improve performance in terms of inventory costs and the risk of stocking out. However, given current carrier schedules increasing frequency is far from being a simple task. Besides, since with traditional Ship-to-Forecast policies each order quantity is based on forecasted demand over the period, the order is intended to cover more frequent shipments rely on more detailed forecasts, which are both less accurate and more variable. As a consequence, more frequent shipments can magnify the bullwhip effect unnecessarily. In the auto industry, attempts to redress this by improving forecast accuracy face daunting challenges and even if they succeed beyond all expectations will have little impact on the problem.

We introduce a new type of policy as an alternative way to deal with variable lead times and inaccurate forecasts. Our Ship-to-Average policy performs at least as well as the more complicated Ship-to-Forecast policies, and also significantly smoothes the order quantities suppliers must manage. Theoretical studies (Ormeci et al. (2008)) indicate this form of policy is optimal in the case of zero lead times, simulation studies based on the parameters of actual component demands at the North American operations of a European manufacturer provide further support and suggest Ship-to-Average policies are at least as good as traditional Ship-to-Forecast policies in terms of inventory and expediting costs. These results are still new and much work is left to do. We are currently working to identify conditions that especially favor Ship-to-Average policies and develop analytic tools for quickly finding optimal policy parameters and assessing the long-term impacts of implementing them.

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