System Dynamics In Business Forecasting:
A Case Study of the Commercial Jet Aircraft Industry

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Abstract

Forecasts of demand, revenues, profits, and other performance measures are a common input to managing a business. And while we intellectually appreciate the difficulties with forecasts, the use of assumptions about the future is inevitable and necessary. Since the forecasts that come from calibrated system dynamics models are likely to be better and more informative than those from other approaches, especially in the mid-term, we must educate our clients to make proper use them.

This paper stress four points:

1. System dynamics models can provide more reliable forecasts of short- to mid-term trends than statistical models, and therefore lead to better decisions.
2. System dynamics models provide a means of detecting changes in industry structure, as part of an early-warning-system or on-going learning system.
3. System dynamics models provide a means of determining key sensitivities, and therefore of developing more carefully thought out and robust sensitivities and scenarios. And,
4. System dynamics models allow the determination of appropriate buffers and contingencies that balance risks against costs.

The paper illustrates that these points with examples from a model of the commercial jet aircraft industry. It shows how the model was used to identify important structural changes in the industry, to avoid unnecessary capacity expansion, and to identify strategies to best "bridge" a business downturn.

Use of Forecasts in Decision-Making Inevitable

The use of forecasts in business is widespread. Estimates of future demand and performance are essential for many business decisions, for example:

- How much to produce;
- How much capacity and other resources will be required;
- What products should be developed; and
- How much financing will be needed by the business.

As a result, most companies devote significant effort to estimating future demand for their products, and to the consequences of that demand on business performance. They rely on numerous econometric forecasting services such as DRI/McGraw Hill, Chase Econometrics, and Wharton Econometric Forecasting Associates, and on internal forecasting and planning staffs. A search of the Dialogweb data base revealed more than 500 publications and journals with "forecast" or "forecasting" in their title. William Sherden, in *The Fortune Sellers* [1998], estimates that the forecasting industry, broadly defined, generates $200 billion a year in revenues.

While the use of models for forecasting is widespread, there is a reluctance in the System Dynamics community to encourage the use of system dynamics models for forecasting. In part, this may be a reaction to the problems with the use of forecasts by businesses:

1. Forecasts are likely to be wrong. Inaccuracies in forecasts of economic growth and inflation are widely documented in the business press [Sherden, 1998]. While some of this error can be attributed to inaccurate or overly simplistic models, as Forrester clearly demonstrated even an accurate model can produce forecasts that diverge from reality. Random elements impinging on a system affect the point behavior of an oscillatory system, and differences in the "noise" streams can quickly produce significant differences in behavior [Forrester, 1961, Appendix K]. Since we cannot predict the random inputs, we cannot predict the behavior of the system.
2. Forecasts are a part of a system's decision structure, and therefore can contribute to problematic behavior. The adverse consequences which often befall businesses and industries as a result of decisions taken on the basis of inaccurate demand forecasts are less widely documented than forecasting inaccuracies, though still common. Barnett [1988] cites several examples:

   - In 1974, U.S. electric utilities made plans to double generating capacity by the mid-1980s based on forecasts of a 7% annual growth in demand. Such forecasts are crucial since companies must begin building new generating plants five to ten years before they are to come on line. But during the 1975-1985 period, load actually grew at only a 2% rate. Despite the postponement or cancellation of many projects, the excess generating capacity has hurt the industry financial situation and led to higher customer rates.
   - The petroleum industry invested $500 billion worldwide in 1980 and 1981 because it expected oil prices to rise 50% by 1985. The estimate was based on forecasts that the market would grow from 52 million barrels of oil a day in 1979 to 60 million barrels in 1985. Instead, demand had fallen to 46 million barrels by 1985. Prices collapsed, creating huge losses in drilling, production, refining, and shipping investments.
   - In 1983 and 1984, 67 new types of business personal computers were introduced to the U.S. market, and most companies were expecting explosive growth. One industry forecasting service projected an installed base of 27 million units by 1988; another predicted 28 million units by 1987. In fact, only 15 million units had been shipped by 1986. By then, many manufacturers had abandoned the PC market or gone out of business altogether.

   Other examples of the use of inaccurate forecasts include:

- "Just three weeks after announcing its new Aptiva home computer line, IBM is sold out through the year end and can't fill all of its holiday orders. The shortage, which IBM attributes to conservative forecasting, means the company could forego tens of millions of dollars in revenue …" [Wall Street Journal, October 7, 1994].

In addition to inaccuracies and potential misuse, the reluctance to use system dynamics models for forecasting may also result from a desire to shift managerial emphasis to understanding and policy design.

However, I believe that the proper use of system dynamics models for "forecasting" can add value to clients. Business will inevitably use assumptions about the future as a basis for most decisions, even if only the "naïve" forecast of assuming the future will be like the past. System dynamics models as forecasting tools can add value to clients in four ways:

1. System dynamics models can provide more reliable forecasts of short- to mid-term trends than statistical models, and thus lead to better decisions;
2. System dynamics models provide a means of detecting changes in industry structure, as part of an early-warning-system or on-going learning system.
3. System dynamics models provide a means of determining key sensitivities, and therefore of developing more carefully thought out and robust sensitivities and scenarios. And,
4. System dynamics models allow the determination of appropriate buffers and contingencies that balance risks against costs.

These points are illustrated with a case example from the commercial jet aircraft industry.[1]

The Case Example - Worldwide Commercial Jet Aircraft & Parts Industry[2]

This work was conducted between 1987 and 1994, first for a manufacturer of commercial jet aircraft, and later for a supplier of parts to a manufacturer. The problem faced by the manufacturer is illustrated in Figure 1: going back to 1970 (and before), orders for commercial jet aircraft exhibited highly cyclical behavior. At the time of the project, critical questions were: Are we at another peak? Should we be adding more capacity? When will be the best time to introduce the next generation of aircraft (i.e., when will the market bottom and grow again). In addition, the client was interested in a number of alternative scenarios: How will future orders, in total and by size category, be affected by the speed and success of "liberalization" of the European airline industry. By growth in the "freight" business? By future oil prices and economic conditions?

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[1] The discussion and focus in this paper is on system dynamics models of markets and market demand, for example, sales of autos, chemicals, commercial aircraft, etc., which are often part of supply chain, or of products with life cycles and/or diffusion dynamics. These models are often developed, instead of or in addition to company models, or company/market models because:

- understanding demand is important and involves complex dynamics
- the decisions to be taken, based on the forecasts, are (seemingly) obvious

market models are less threatening, and more standard procedure, than company models (especially "policy" or strategy models).

[2] Contributing to this project at Pugh-Roberts were, in addition to the author, Rick Park and Bill Dalton.

As illustrated in Figure 2, the industry has characteristics similar to a supply chain or production-distribution system.[3] Starting at the left of the figure, economic conditions (GDP, personal income) generate travel demands for business and leisure. These demands create demand growth which drives changes in the airlines' fleet utilization. Changes in fleet utilization cause airlines to change their orders for aircraft, and so on down the chain. Figure 3 shows that the system creates amplification down the "supply" chain.

The dynamics of the industry, at the simplest level, are illustrated in Figure 4. There is one major "negative" or balancing feedback loop and three amplifying positive loops. Starting on the left of the figure, travel demand (revenue passenger kilometers or RPK) is influenced by GDP and population (exogenous inputs), by fares, and by travel experience. For example, suppose that GDP increases, inducing an increase in business and recreational travel. Two reinforcing feedback loops amplify this increase in the short-term: (1) as demand goes up, given that a significant fraction of airline costs are fixed, target fare required to maintain the same profitability can go down – the airlines can spread their fixed cost over more passenger kilometers; as the airlines reduce fares, the positive stimulus from the economy is reinforced; and (2) an "experience effect" further reinforces the economic stimulus – the more people fly, the more they get used to flying, and so they fly more (or are reluctant to reduce flying in a recession).

As demand for travel grows, the airlines begin to project demand forward (forecast!). They decide how many aircraft they will need to meet that demand, and compare that to their fleet. They order aircraft to meet that gap, which introduces another reinforcing feedback loop – as the order backlog approaches manufacturing capacity, delivery lead times increase. Instead of taking two years to get an airplane, it now takes three. As a result, airlines order further ahead. As they order more, because manufacturing capacity is slow to increase, delivery lead times increase further. As lead time increases, airlines order more aircraft and sometimes "play games" in order to get a better position in the delivery queue. For example, they might order aircraft from different suppliers, with the intent of canceling or delaying one after the first arrives. These ordering policies, in combination with the stimulus of price and experience to demand, creates over-expansion in the industry.

After a while, orders are delivered and enter the fleet. This raises the airlines' fixed costs, and fares must increase to cover these costs. Fare increases put downward pressure on demand growth. It happens that the cycle delays around the manufacturing delivery loop are three to five years, which corresponds well to the business cycle. So just as fares are increasing with the growth in the fleet, often GDP is going down. This triggers the downwards spiral with the reinforcing price and experience loops, not to mention all those airplanes ordered that are still being delivered! The dynamics just described are the essential causes of cycles in the aircraft manufacturing industry.

However, there are additional feedbacks. As illustrated in Figure 5, the used aircraft market often acts to amplify cycles. When new, replacement aircraft are delivered, the used fleet increases. This creates a supply to absorb further demand, and acts to depress prices and encourage the purchase of used rather than new aircraft, thereby prolonging a downturn. In addition, as shown in Figure 6 financial dynamics (cash flow and profitability) act to reinforce

[3] The boxes are stylistic, and do not denote levels.

cycles -- when the industry is in an upswing, high profits and cash flow encourage investment, and conversely when the industry declines.

While the dynamics described above create the cycles in the aircraft industry, such a simple model would not have served our client's needs. Detail and calibration were necessary to answer questions about the timing and size of the peak, the need for more capacity, and the prospects for particular size categories of aircraft. Detail was added to the model (see Figure 7, a more detailed "block" diagram of the model of the industry): demand was disaggregated into domestic and international components (different size and operating characteristics of the aircraft), and into major regions (because of significantly different growth potential). Airlines were similarly disaggregated by region. The used market, leasing companies, and prime manufacturers were added. The same basic dynamic structure underlies the detail.

In some cases forecast policies are built into a model, and in others they are represented by "exogenous" decision inputs. In this model, the forecasting of travel demands and aircraft required by the airlines is built into the decision structure of the model. However, forecasting by the manufacturers for capacity expansion was not included dynamically in the original version of the model (it was later added for the work done for the parts supplier). Rather, manufacturing capacity was input exogenously as a means of testing alternative scenarios ("What if other manufacturers expand more, or less, aggressively?"), and options for our client ("How much capacity should we add?" "When, and in what sizes?").

The model was calibrated to historical data, and used to produce a forecast of future orders by the airlines. Initial simulations with the model indicated that the peak in orders was at hand (as indicated in Figure 1). However, although hard data was not yet available, anecdotal evidence, and order data at our client, indicated that orders for aircraft were still increasing. After further discussions with marketing and sales people at the client, we determined that a significant structural change was occurring: leasing companies, which had previously been strictly financers of aircraft ordered by the airlines, were now placing significant orders for their own "fleet," to be leased to the airlines on an operating basis. As a result, structure was added to the model to reflect this change (see Figure 8). Two key assumptions were required to represent this: (1) the "market share" targets of the leasing companies; and (2) how long it would take for the airlines to reflect this change, and what fraction of this capacity they would include in their ordering decisions. Best estimates were obtained from our client, and this became the basis for the "Base Case" forecast shown in Figure 9.

With the detailed and calibrated model, we were able to accurately predict first the peak, and then the downturn. As a result, our client avoided unnecessary capacity expansion because it was clear that a significant portion of the orders in the 1989 peak were positioning or double orders, and would be canceled or delayed when the bottom fell. They were also able to introduce a new family of aircraft into the upturn. Having a detailed, calibrated model that produced accurate forecasts resulted better decisions and significant savings to the client.

System dynamics models can provide more reliable forecasts than statistical models

The system dynamics model was able to quite accurately forecast the cyclical peak, and the subsequent downturn. While not all forecasts turn out as accurate as those shown in Figure 9, the system dynamics model offers the potential for greater accuracy than statistical models which tend to be based largely on macro-economic factors. This is because industry behavior is driven by industry dynamics, not by changes in macro-economic factors.

In another project modeling the North American helicopter market, we developed a regression model relating helicopter sales to GDP growth and oil prices.[4] The best fit was obtained with:

> Helicopter Sales = f[GDP Growth Lagged One Year; Oil Price Change Lagged One Year]

The best fit produced a correlation coefficient (R^2) of 0.4, which does not inspire great confidence.[5] The time series output of this regression is illustrated in Figure 10 – while showing some cyclicality, it significantly misses the severity of the peak and trough. The simulation output, based on a model dynamically similar to that described above, captures the behavior much better (with and R^2 of 0.84).

In a dynamic industry, a well-calibrated model which captures those dynamics can be an accurate short- to mid-term forecasting tool. Such models tend to be insensitive to exogenous driving inputs such as GDP or oil prices. For example, Figure 11 shows the forecast produced by the model to several different input assumptions:

- "Flat" GDP growth between 1987 and 1995, at the actual average for those years;
- A more cycle in GDP closer in amplitude and timing to historical cycles than actually occurred; and
- A decline in real oil prices of 1% per year (close to what actually happened), rather than the assumed increase.

The forecast is largely insensitive to these inputs.

However, the forecast is sensitive to industry dynamics. Figure 12 compares the Base Case to two simulations in which key drivers of industry dynamics were neutralized from 1987 on:

- the leasing company's as owners of aircraft were removed; and
- manufacturing delivery delay remained at the 1987 value.

In both cases, the "forecast" provided by the model would miss the peak and trough significantly, both in timing and amplitude. A calibrated model which captures industry dynamics is capable of providing very good short- to mid-term forecasts.

System dynamics models provide a means of detecting changes in industry structure

If a well calibrated model is capable of providing very good short- to mid-term forecasts, then that model becomes a means of detecting changes in industry structure. As new data and other information become available, they are compared to the model's forecast. When significant deviations are detected, the model provides a means of determining the source of

[4] This example was developed by Richard Park and Henry Weil.
[5] R^2 was used because it is sufficient for illustrative purposes. A more rigourous statistical test such as the Theil statistic, which separately measures phase correlations, standard deviation, and mean errors, would reinforce the conclusions drawn here.

the deviation. If sufficient time has passed since the last model update, it is possible that changes in external inputs might have caused the simulation to deviate from actual behavior. Alternatively, industry structure might have changed in some way. For example, the sensitivity of the airlines to growth trends, profits, and delivery delays might have changed, perhaps because there are many new entrants, or because the industry has consolidated.

One example of such structural change, the emergence of the leasing companies as owners of aircraft, was described above. In that case, the change required adding new structure to the model. Another example was the de-regulation of the US industry in 1979. Representing this required changing a number of parameters in the model which reflect airline decision-making, including:

- preference of the airlines for increased flight frequency over fewer flights with larger aircraft;
- willingness to absorb a short-term reduction in load factors and operating margins in order to gain market share; and
- competition increased the sensitivity of ordering to growth rates and to increases in manufacturer lead time.

As the industry seems to be re-consolidating, some parameters in the model may again need to be changed to reflect this.

The purpose of the use of forecasts in this way is to foster improved, early understanding of changes in the environment, as a guide for designing adaptive mechanisms.

System dynamics models provide a means of developing more carefully thought out and robust sensitivities and scenarios.

Understanding of dynamics, and the ability to do simulations and full sensitivity tests, allows us to:

- Determine those uncertainties to which the forecast is most sensitive -- the real risks;
- Provide more reliable, or better thought out ranges for the “forecast” and scenarios, given the key uncertainties (and even probabilities for those ranges)

For example, when we made our initial projections with the model in 1987-88, assumptions regarding leasing companies could only be estimated. However, recognizing their importance to the forecast, the client examined a plausible high-low range. This is illustrated in Figure 13. While the precise assumption affects the point forecast, it was clear from these results that with high degree of certainty the industry would experience significant over-ordering in the 1989-90 peak. This gave the client the confidence to abandon plans to add significant extra capacity.

Also, in light of the knowledge gained from the US experience, the model can help to better define the range of possibilities for a Euro-liberalisation scenario.

System dynamics models allow the determination of appropriate buffers and contingencies

System dynamics models allow the determination of appropriate buffers and contingencies that balance risks against costs. Forecasts will be inaccurate, and the successful companies will be those that recognize this and provide the necessary buffers and contingencies. However, most buffers and contingencies are involve costs, and therefore some idea of the range of uncertainty with which they have to operate would allow companies to design cost-effective buffers.

For example, entering the last downturn, a supplier to a maker of jet aircraft needed to establish policies for “bridging” the downturn. Such a “bridge” might include:

- keeping the existing labor pool, and maintaining production to build a semi-finished inventory;
- keeping the existing labor pool, but forcing “vacation” as necessary (with and/or without pay) to minimize inventory;
- building parts and WIP inventories; and/or
- keeping supplier capacity in reserve for the upturn.

In addition to the market model, we developed a separate model of the supplier’s manufacturing system, including:

- labor productivity and how it is affected by experience, morale, overtime, learning, parts availability, and so on;
- labor supply, including delays in recruiting and training new workers; and
- parts supply, including delays in supplier production and capacity expansion.

The market model was used to determine a range of forecasts for input to the manufacturing model. The range of plausible demand inputs is illustrated in Figure 14. A set of tests were conducted against these inputs, first assuming the traditional policy of laying off workers and cutting production rates, and then against several “bridge” options (see Figure 15):

1. Full-bridge – do not lay off any workers (attrition will reduce some), and build semi-finished inventory;
2. Half-bridge – gradually lay off about half the workers that would have been traditionally laid off; and
3. Quarter-bridge – gradually lay of three-quarters of workers.

Figure 16 compares the percentage change in cumulative, discounted profits from 1994 to 2000 under these alternatives. Clearly, the “optimal” strategy depends on what actually happens to demand:

- If demand growth is expected to be slow, bridging does not make sense – any productivity savings are offset by inventory carrying costs;
- A half- or full bridge makes sense if demand growth is expected to at least be moderate; and
- A full bridge is clearly superior only if the recovery is expected to be fast.

Analysis of model forecasts indicated that demand growth would most likely be in the moderate to base-case ranges. Faster growth was highly unlikely – this occurred only if airline profitability recovered very quickly, or if airlines were less conservative than historically in rebuilding their balance sheets after the downturn. No one felt that this was likely. Slow growth or worse only occurred in scenarios where the manufacturer of this particular aircraft replaced it with either a newer, smaller aircraft, or with a combination of the smaller aircraft and an even larger plane. Neither of these scenarios seemed likely. With increased congestion at airports and traffic systems, the number of flights required to serve simulated demand if the aircraft were completely replaced with a smaller plane did not seem feasible. Further, while the combination of the smaller and larger planes would solve the congestion problem, the development costs of a larger plane seemed beyond the reach of aircraft manufacturers for the foreseeable future. Therefore, the slow growth scenario seemed unlikely.

The forecast range from model, and more importantly, the reasons for the forecast differences, narrowed the likely range such that an "optimal" policy for the likely range of demand could be determined. Although our client did not go as far as we felt was justified, the power of the logic of the forecasts gave them the courage to adopt a new policy for bridging the downturn.

PERFRORMANCE IMPROVEMENT "FORECASTING"

The case has been made that system dynamics models can be used effectively as forecasting tools for market and company demand. In addition, system dynamics models can provide effective forecasting of the performance improvement that should result from a strategic initiatives, investments, or policy changes.

Strategic analyses are often initiated after a company experiences a "crisis". System dynamics models can provide a useful tool for diagnosing the real causes and identifying high leverage areas for improvement. The models, if properly calibrated, can then provide a forecast of the expected change in performance resulting from the selected initiative (including any "worse-before-better" behavior) [see Lyneis, 1998]. This can be important because:

1. Investments are often required – with any policy change or investment, the expected pay off must be big enough to justify the risk, and a system dynamics model allows one to compute that payoff;
2. If "worse-before-better" behavior will occur, understanding the reasons and likely magnitude can help a company get through the tough times without abandoning implementation; and
3. Forecasts provide a necessary component of any early warning/learning system – deviations between the forecast and new information/data allow the company to analyze the possible reasons and identify potential changes before the competition.

Conclusions

All business decisions are based on forecasts, or assumptions about the future. By capturing the causes of industry dynamics, system dynamics models can provide better forecasts than traditional approaches. In and of itself, this should allow managers to make better decisions. But in addition, the use of system dynamics models for forecasting allows managers to: (1) get an early warning of industry structural changes, (2) identify key sensitivities and scenarios, and (3) determine appropriate buffers and contingencies for forecast inaccuracies. These benefits can further enhance business performance.

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Figure 1 World-wide orders for new aircraft are highly cyclical.

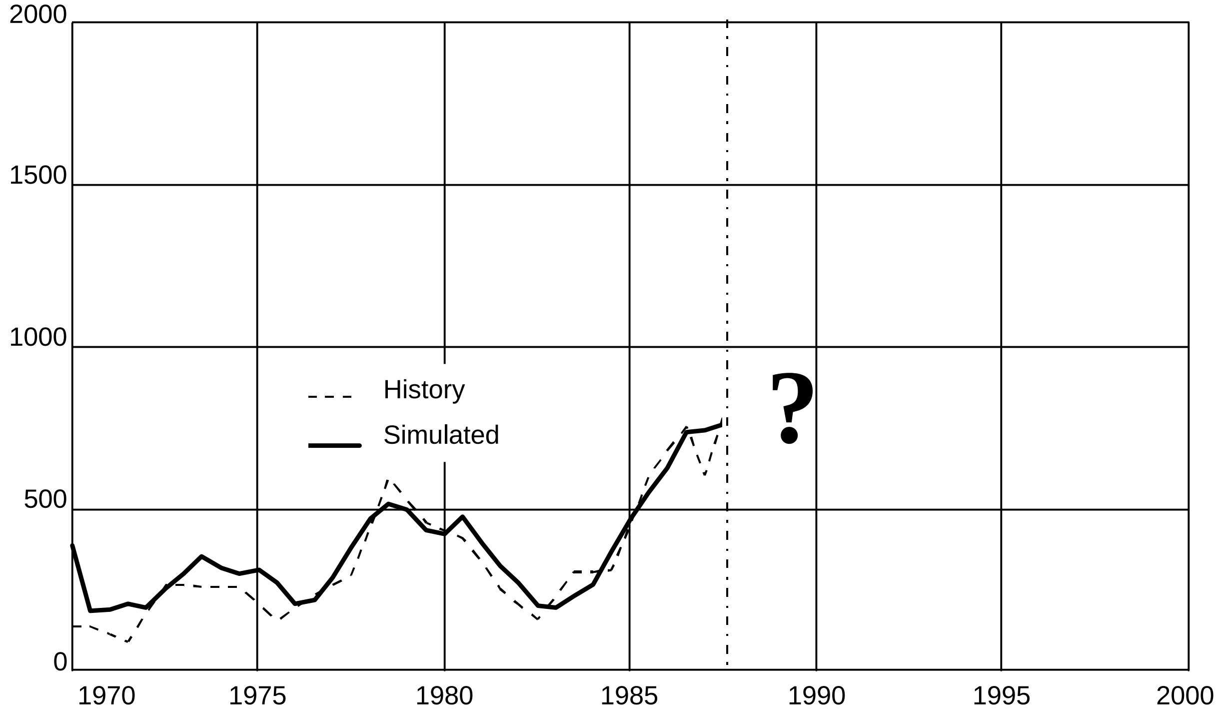
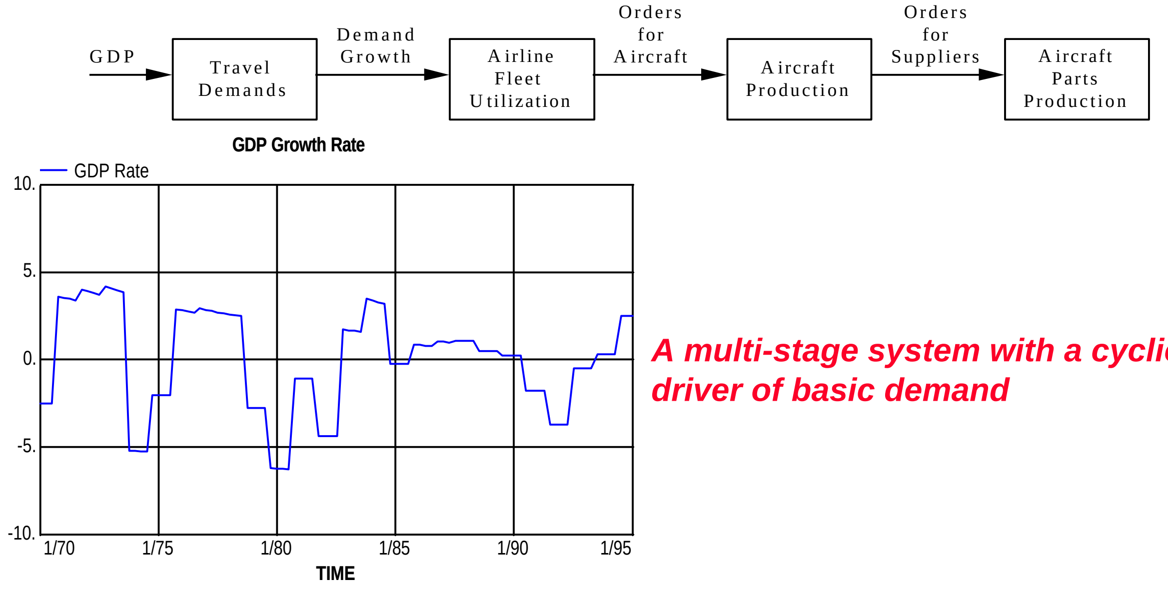


Figure 2 Industry supply chain.



A multi-stage system with a cyclical driver of basic demand

Figure 3 Amplification down the supply chain.

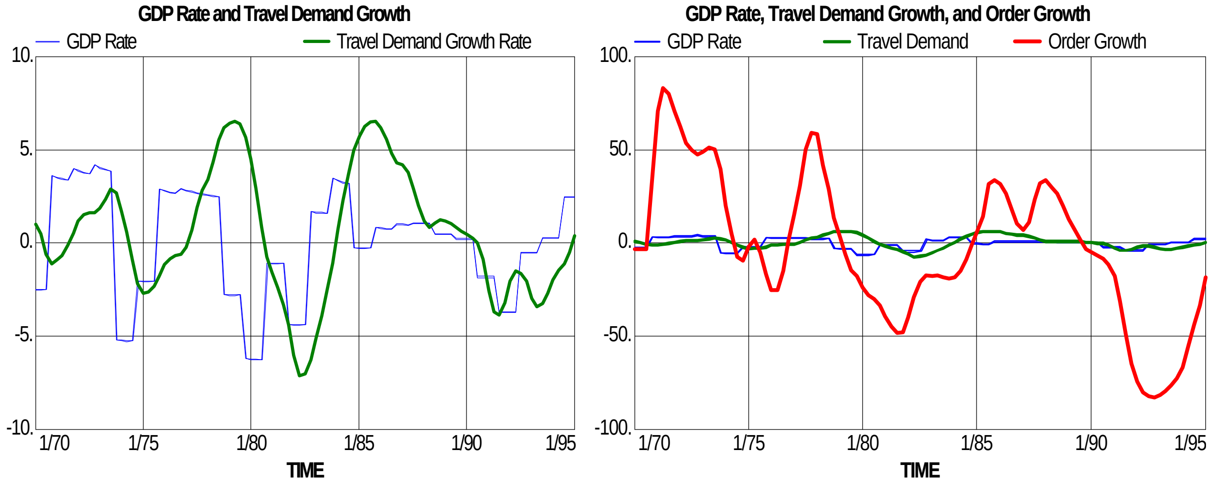


Figure 4 Basic dynamics of the industry.

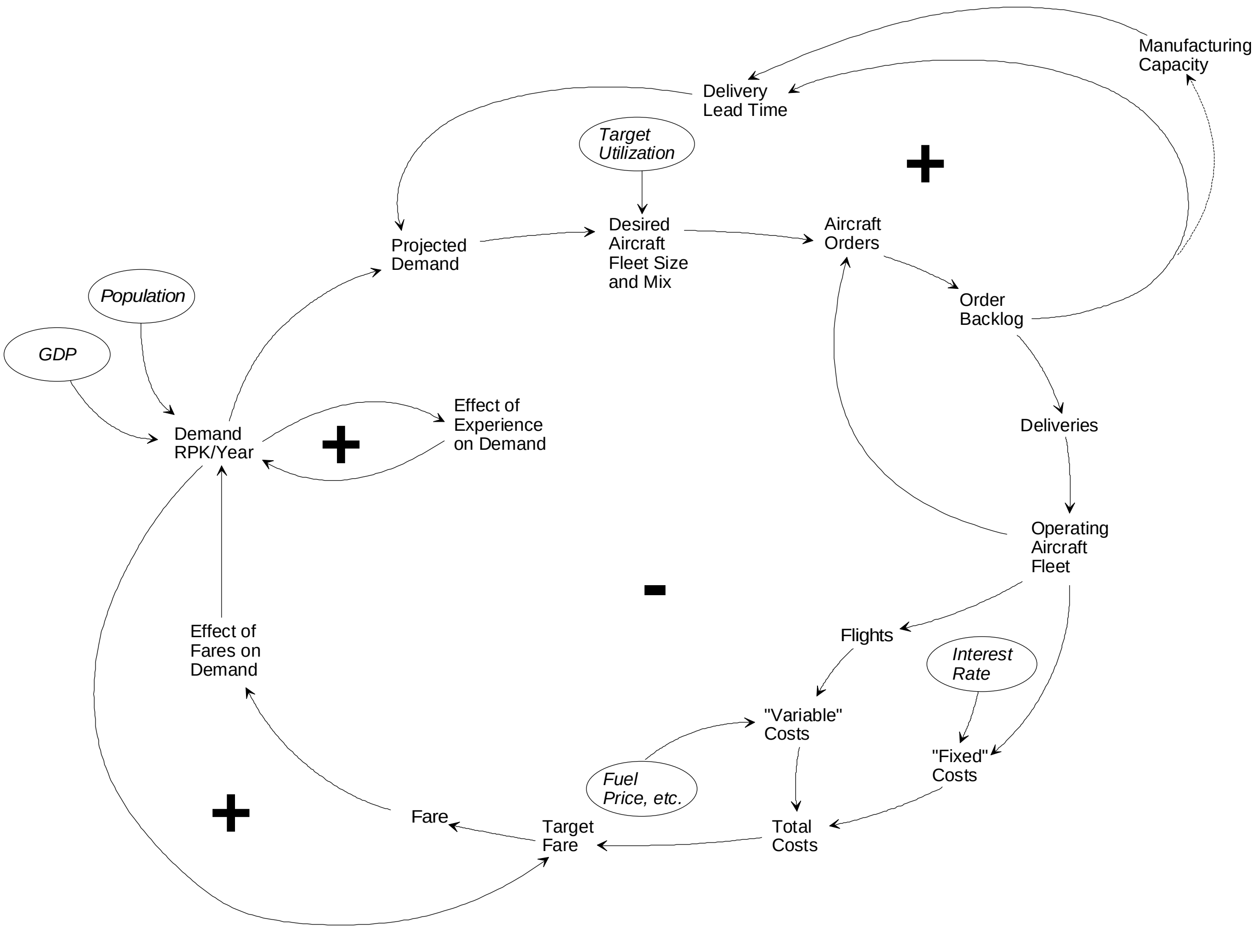


Figure 5 The used aircraft market amplifies the cycles.

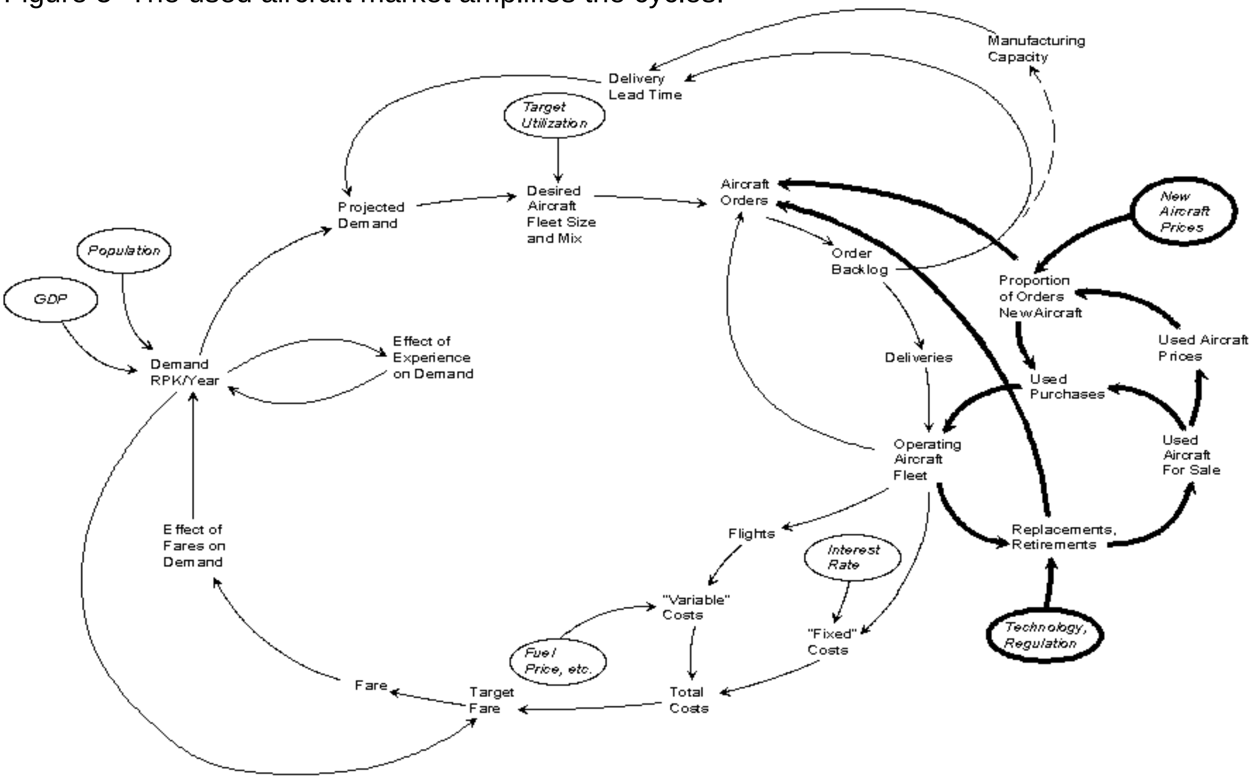


Figure 6 Financial dynamics also reinforce cycles

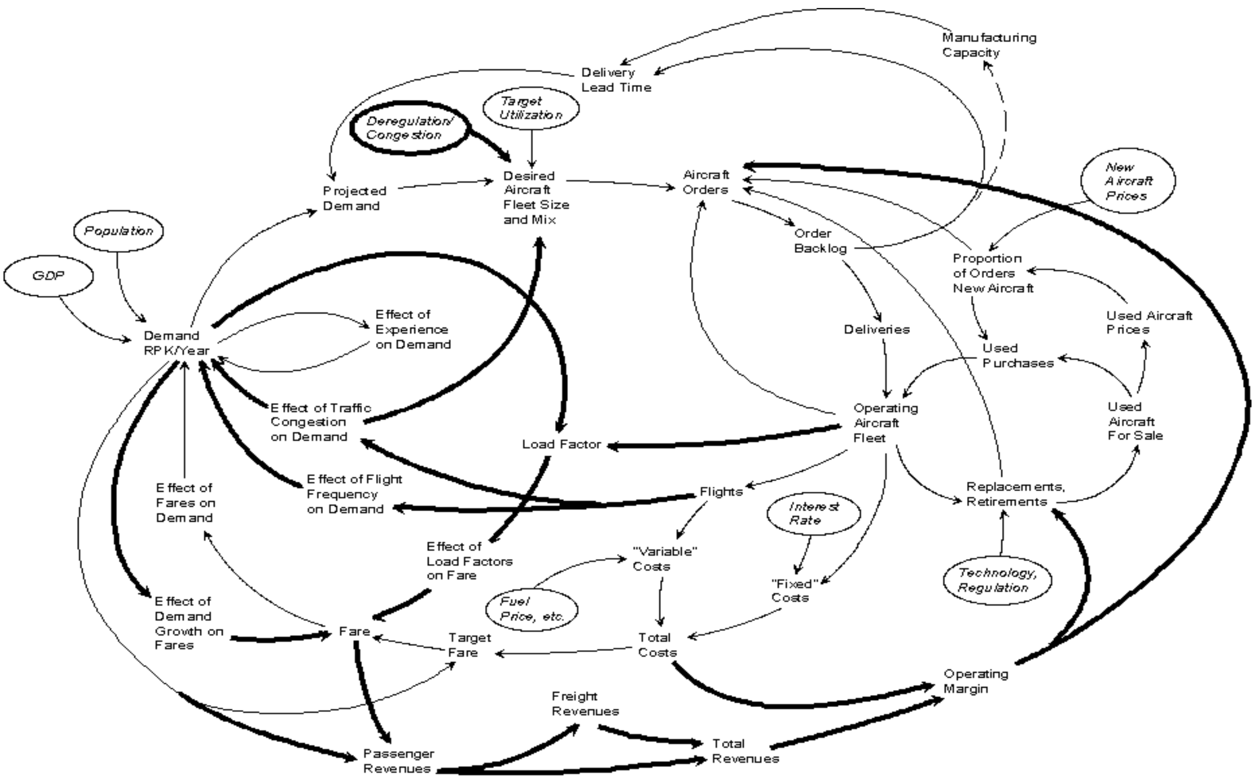


Figure 7 Structure of industry.

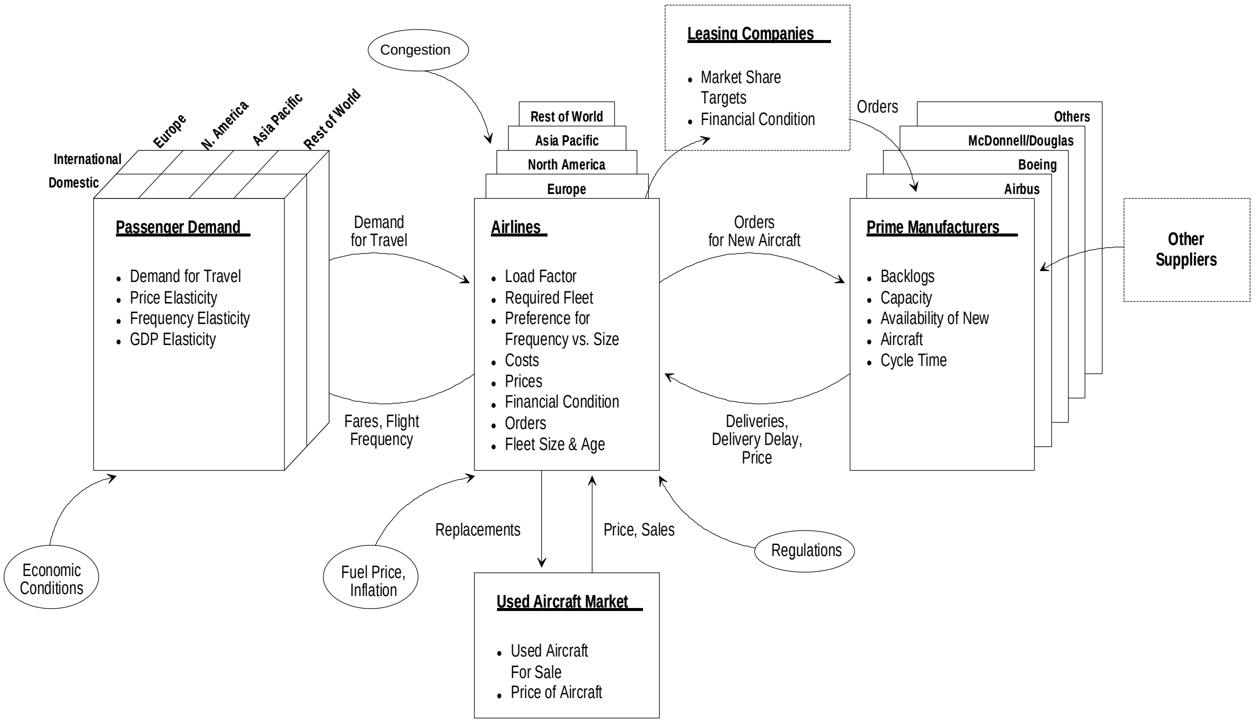


Figure 8 Leasing company structure.

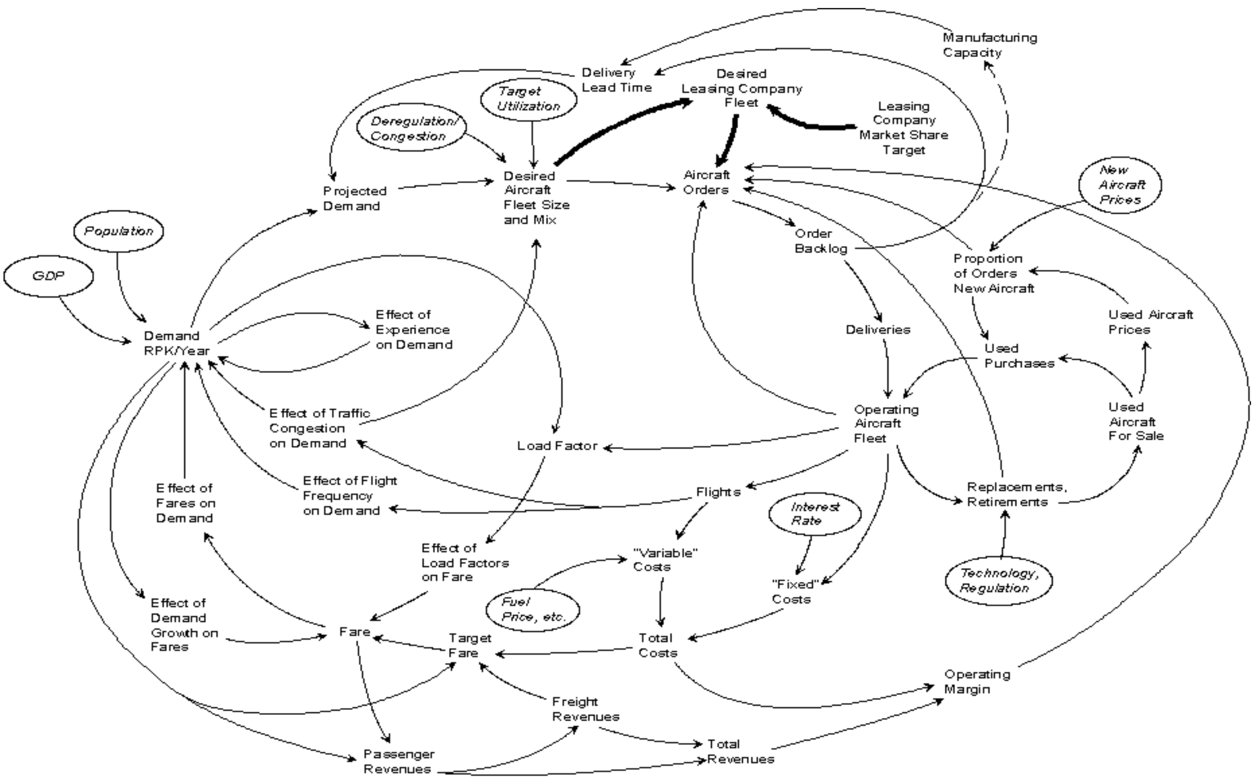


Figure 9 Base Case forecast.

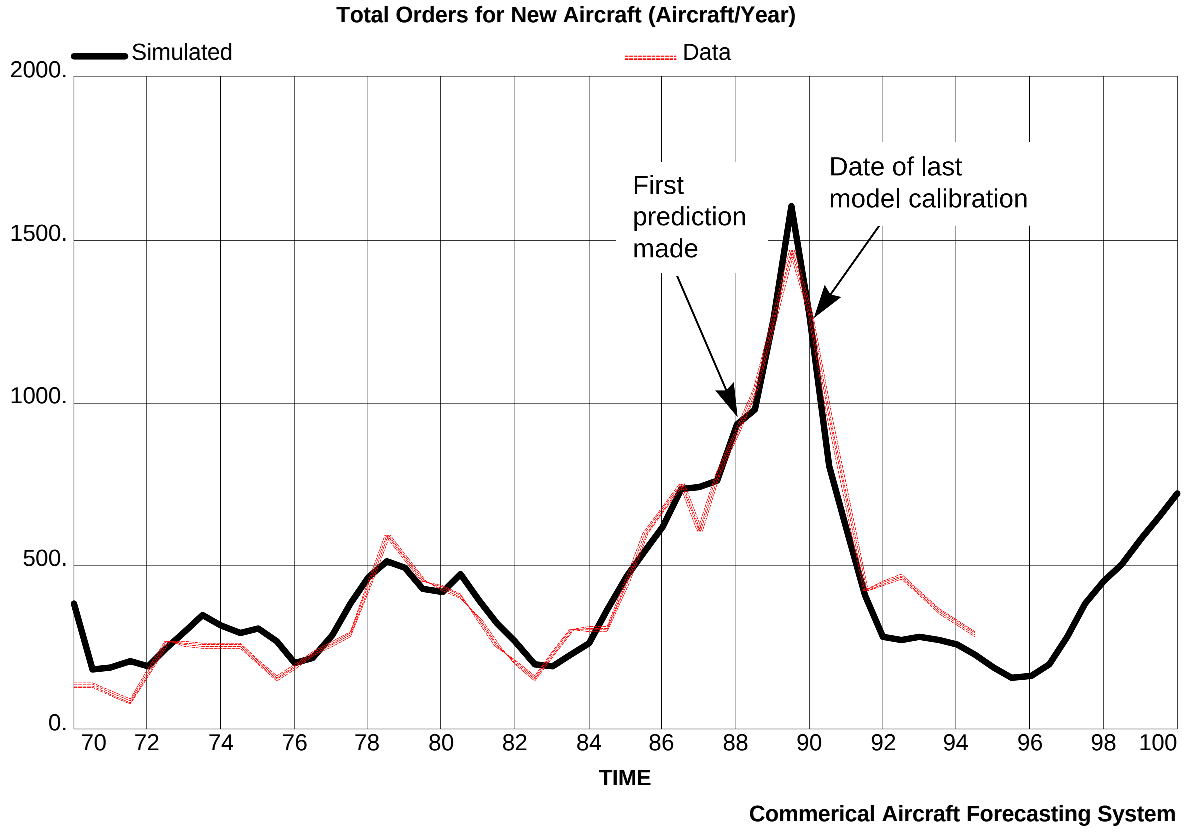


Figure 10 Regression fails to capture peak orders in helicopter market.

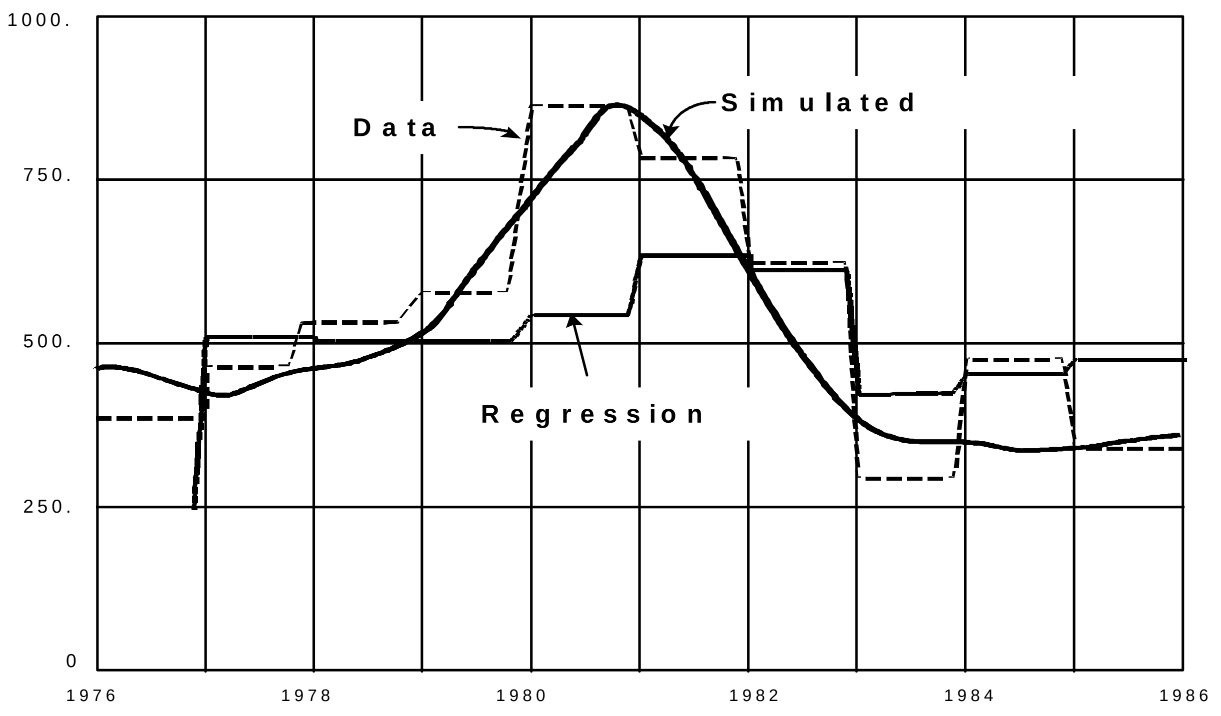


Figure 11 Sensitivity of forecast to input assumptions.

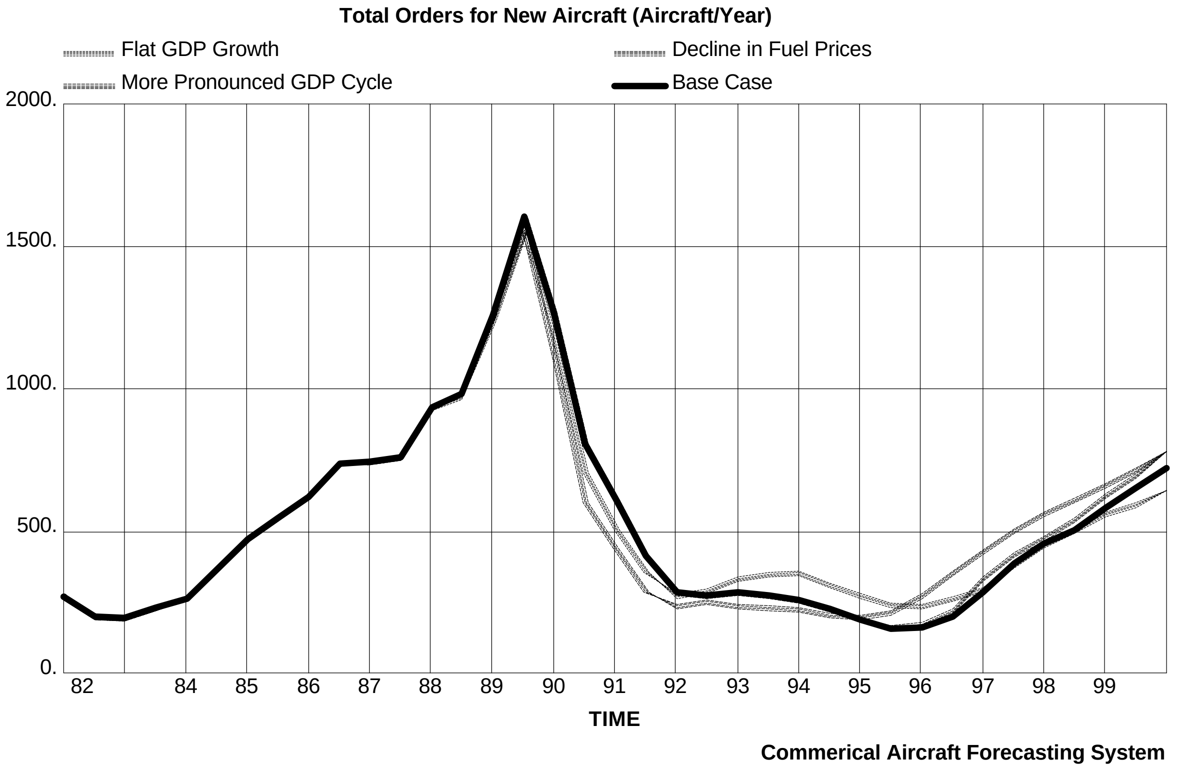


Figure 12 Sensitivity of forecast to industry dynamics.

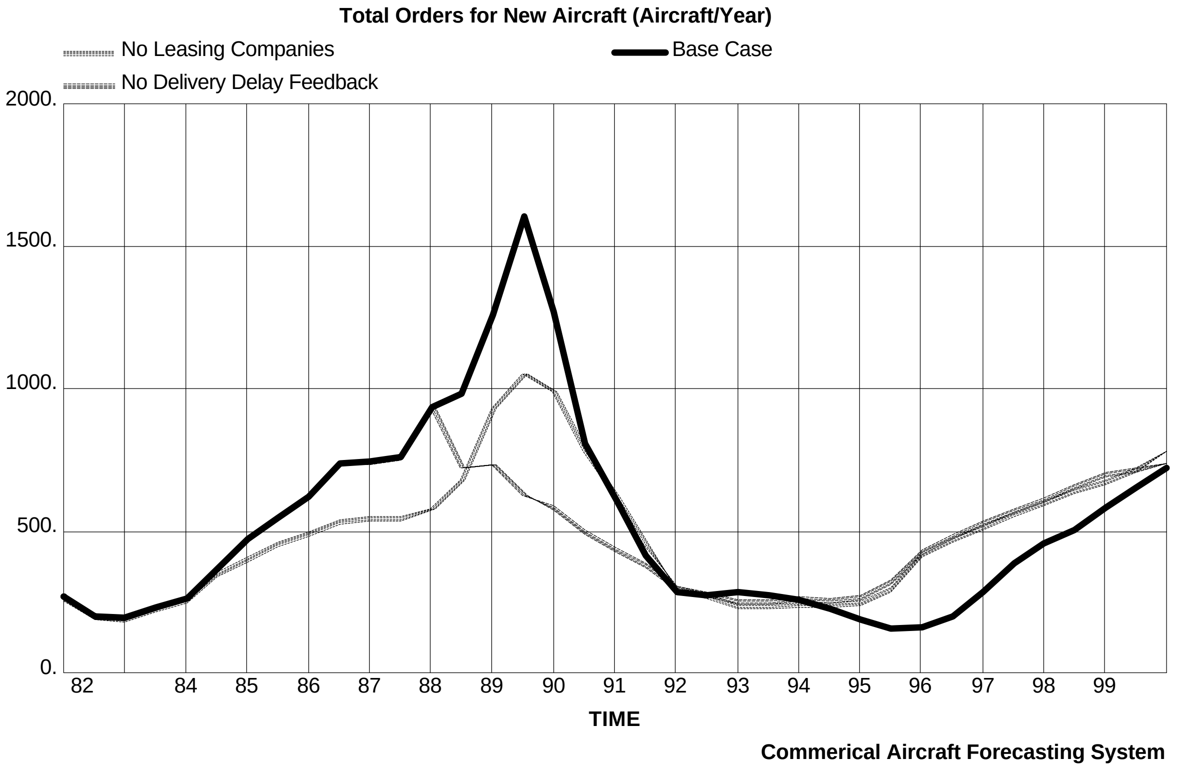


Figure 13 Sensitivity of forecast to leasing company assumptions.

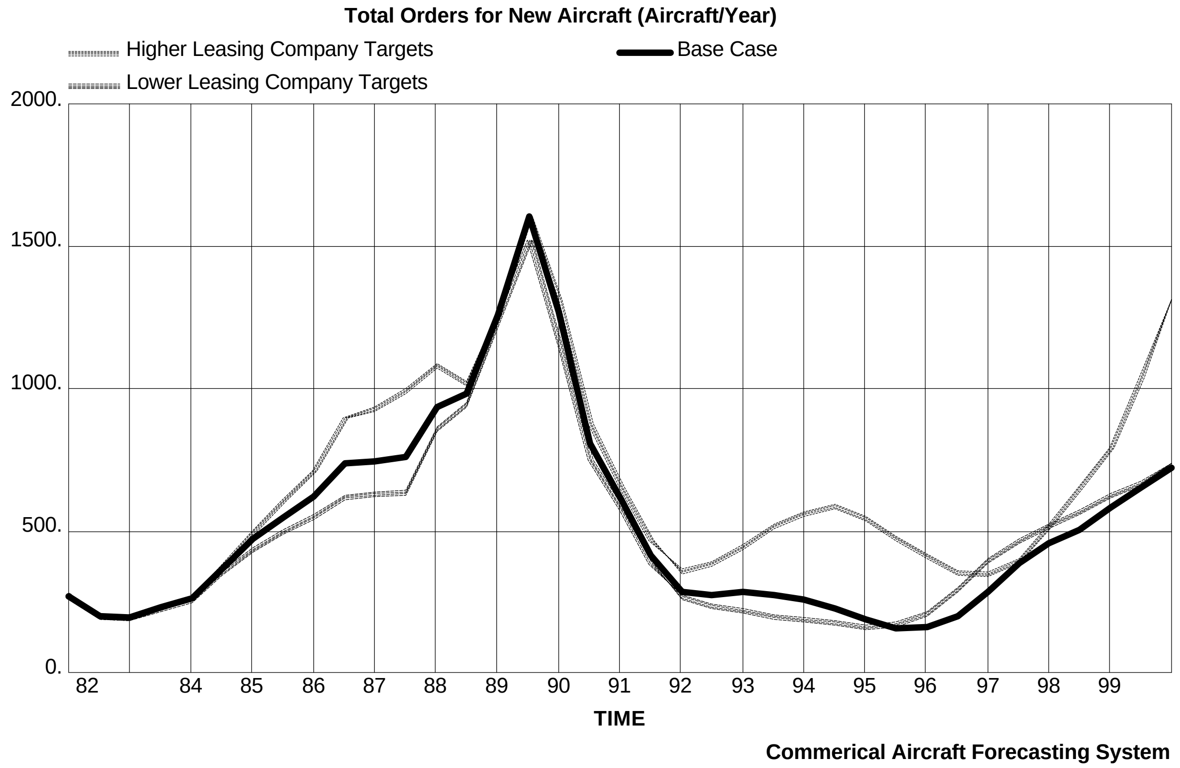


Figure 14 Demand scenarios.

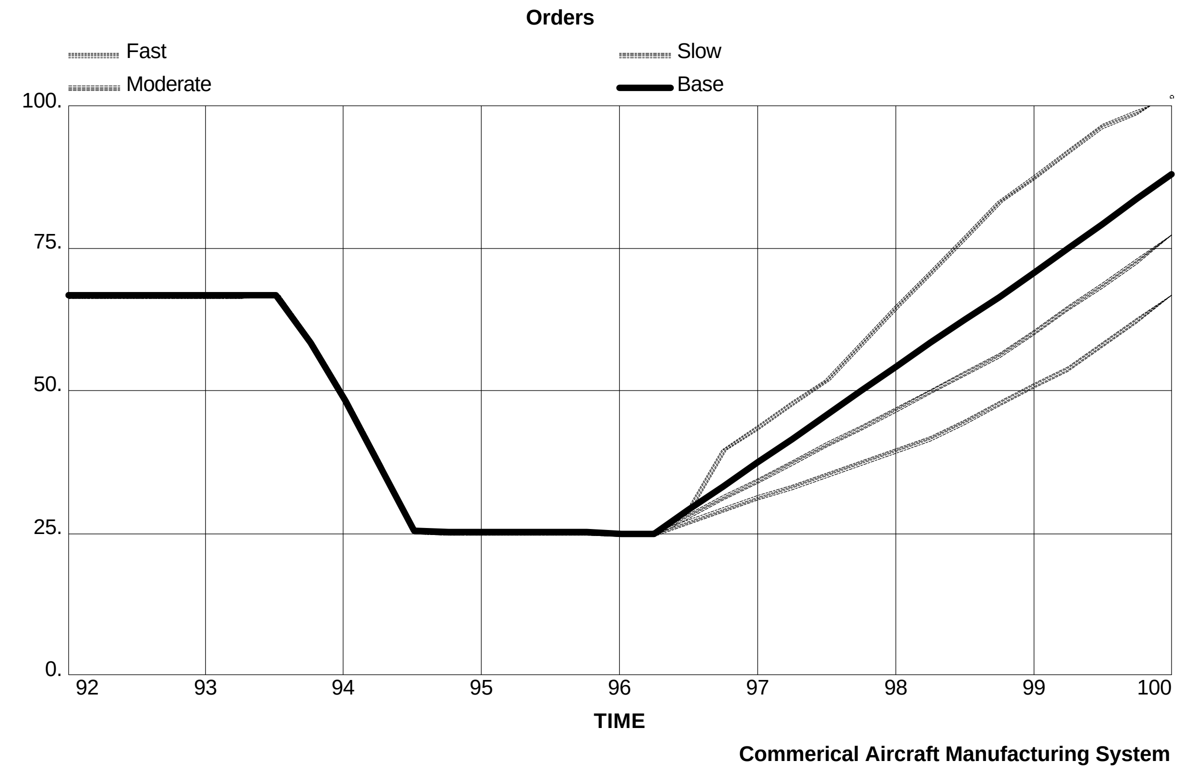


Figure 15 Employment levels under different bridging strategies.

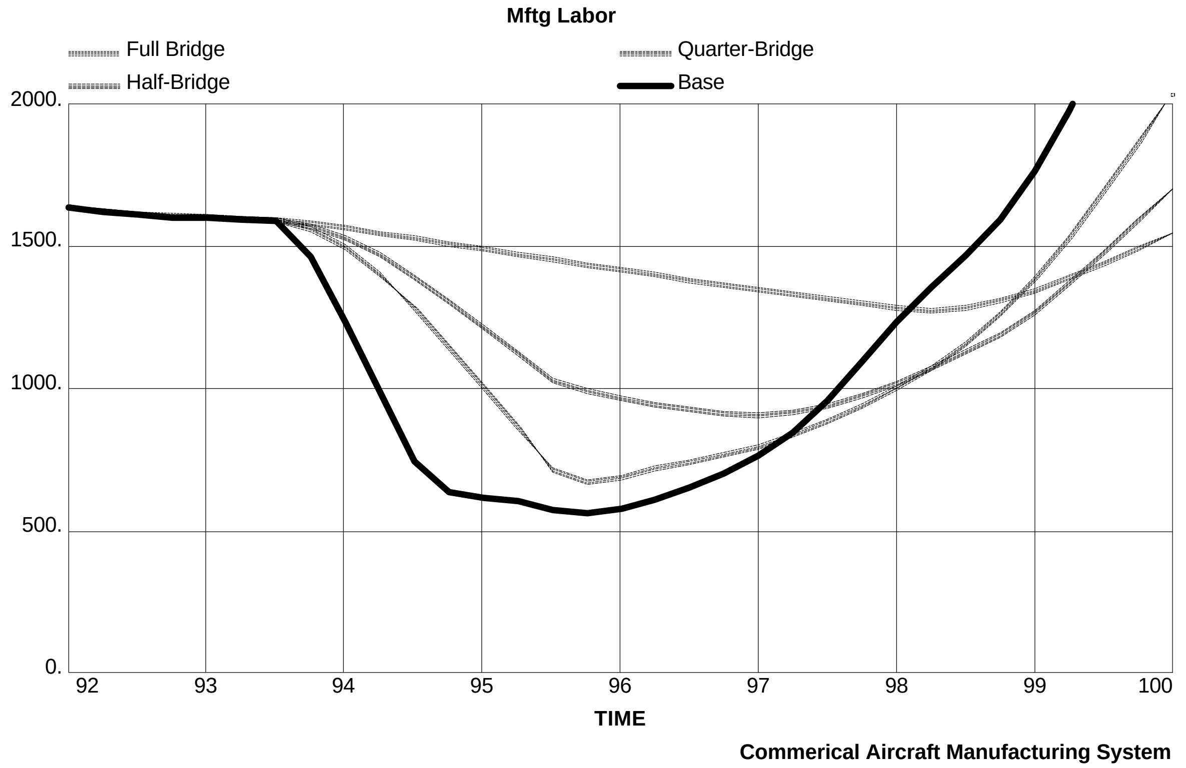


Figure 16 Change in profitability under different bridging strategies.