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A Case Study of Pratt and Whitney Aircraft's Commercial Spares Planning

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ABSTRACT

This case study, which can be used as a teaching case, deals with jet engine spare parts planning at Pratt and Whitney Aircraft Company, a division of United Technologies Corporation. The case includes background on the company's history and an overview of their jet engine manufacturing operations. The primary focus of the case is on the application and evaluation of forecasting models for demand planning within an ERP system environment. An Excel-based decision support system (DSS), which is available from the authors upon request, enables the evaluation of alternative time series forecasting models for a variety of jet engine spare parts. The DSS workbook replicates the many features and options available in SAP's forecasting system, which has been purchased by Pratt and Whitney.

INTRODUCTION

Larry Hosey, Manager for PW2000 engine spares at Pratt & Whitney, quickened his pace to attend the planning meeting for the commercial jet engine spares business. He was meeting with John Doyle and Greg Campagnano, his counterparts responsible for the JD8D and PW4000 jet engine spares. There had been a number of recent changes in the business and new procedures needed to be developed for managing this complex function.

During the meeting, the following comments were put forward:

John Doyle: "Our commercial spare parts division is a make-to-stock business and our ability to support the customer depends heavily upon having material available off the shelf. Our customer catalog advertises a seven-day lead- time on the majority of our parts, so the expectation is that our customer can get his orders filled within that time frame. It is then incumbent upon us to make sure that we have the right amount of inventory on the shelf to support that seven-day lead-time. The recent events of the airline industry have put an even enhanced burden upon us to try to come up with the best forecast possible."

Greg Campagnano: "We have close to 22,000 parts that need routine forecasting. About two-thirds are forecasted based upon historical sales data using simple time series models, with the rest done manually. Manually forecasted parts are typically very expensive items or with very low demand. For example, we have one turbine case that has a current list price of over a million dollars. Therefore, we try to approach these types of items on as much of a "Just-In-Time" basis as we can. There are a number of factors influencing demand for those parts, and we solicit information both internally and externally from customers to help us do the planning for those items. A major input to the forecasting process involves gathering data from the customers. We conduct planning and forecasting conferences with the major customers, the major operators and shops, whereby we sit down with them and discuss what their parts needs are, what they see changing, and it is very helpful to us."

Larry Hosey: "The Spare Parts supply chain starts with a forecast which is done on a part number level. This forecast is input into the SAP system, which generates an MRP schedule to our internal producers, which we call module centers because they each make a module of the engine and the parts that go into it. The module centers then select internal or external suppliers to do the work for them. These manifest themselves into deliveries to a distribution center, located in Georgia, which is then responsible for all of the commercial spare parts throughout the world. Generally the lead-time involved in creating these parts ranges anywhere from two weeks to about nine months – that's a considerable span. Also, there are considerable differences on the types of parts that are stored, and the costs of the storage of the parts.

Because we forecast 22,000 individual parts, in 2003 we implemented an APO system-bolt on to SAP, which we purchased. It is going to afford us the opportunity to have a bit more flexibility relative to how we model our time series demand, because many of our parts are based on the demand history. In an attempt to improve our forecast, the APO tool provides us about 36 statistical models, which is far more than we use today. Right now we're at the infancy stage of how to use them and which of 22,000 parts fits best with which model. That's one of the efforts we've got afoot, trying to classify parts in such a way as to understand how best to use the tool we have in place."

While commercial spares are sourced from both internal P&W and external suppliers, all stock was consolidated outside Atlanta (GA) at a single location for rapid shipment to customers worldwide. A 95% service rate had been established for the business, but there was significant pressure to be effective and minimize spares inventory investment levels. With over 22,000 items in the division's catalog that Pratt & Whitney commercial spares business supplied, planning for the appropriate stocking level to meet customer demand was challenging. For most items, a seven-day delivery lead-time was specified for stock items. For very low demand and expensive items (above $1 million), a thirty-day lead-time was targeted.

COMPANY HISTORY AND BACKGROUND

Frederick Rentschler established the Pratt & Whitney Aircraft Company in July 1925 to design and build aircraft engines. The Pratt and Whitney Tool Company, in Hartford, Connecticut provided startup money, factory space, and even a name for the new company. Six months after formation, the new company produced the Wasp engine, which included a number of important advances for the Navy. The Wasp and its successor, the Hornet, were utilized extensively in Navy aircraft for many years and dominated the civil market.

By the early 1930s, Pratt & Whitney Company was building the Twin Wasp. This engine powered many fighters, bombers, and transports of the period. As WWII progressed, technology advanced and more powerful engines became common. Pratt & Whitney produced both the Twin Wasp and the Double Wasp R-2800, which powered much of the U.S. fighter and transport fleet as well as many British planes. While the jet engine was developed during WWII, Pratt & Whitney had spent the war years focusing exclusively on its piston engines. By 1945 it was far behind competitors who had been developing jet engines.

In 1952 P&W introduced the J57 turbojet in a B-52 bomber. The commercial version of the J57—the JT3 engine—powered Boeing's first jet transport, the 707, and the Douglas DC-8. Over the next four decades a number of new jet engine designs (JT8D, JT9D, PW2000, PW4000, V2500, GP7000 and PW6000) were added to the division's product offerings to support the commercial aviation industry. By the mid 1990s, Pratt and Whitney had over 15,000 installed commercial jet engines serving close to 500 domestic and foreign customers.

Pratt & Whitney today, a division of United Technologies Corporation, is a large American aircraft engine manufacturer, with their engines widely used in both civil and military aircraft. Commercial air giants Boeing and Airbus are Pratt & Whitney's largest airframers. They serve P&W's airline customers worldwide. P&W has several commercial engine families including the JT8D, the JT9D, the PW2000, the PW4000 and the PW6000. Their military offerings include engines for the F/A-22, the F-15, the F-16, the C-17, and the Joint Strike Fighter currently being developed. Pratt & Whitney, General Electric and Rolls-Royce are the primary players in the market, with Pratt & Whitney being more successful in the wide-body aircraft like the Boeing 777 and the Airbus 330. General Electric enjoys a significant lead in the narrow-body market supporting such planes as the Boeing 737, with Rolls-Royce producing engines for both markets.

Today's commercial aviation industry is faced with a number of competitive concerns, including significant price competition, a need for more efficient engines, and a significant amount of over capacity. The 9/11 tragedy significantly changed the operating characteristics of the aviation industry. Many new planned orders have been cancelled. Numerous airlines have lost billions of dollars a year over the last decade with many major airlines like United Airlines and US Airways going into Chapter 11 bankruptcy. With higher fuel bills, the need to reduce operating costs led to calls by management for even better engines. However, this will not occur quickly. The manufacturing of aircraft engines is technologically intensive and subject to lengthy and costly development cycles. It can cost as much as $1.5 to $2 billion to bring a new engine design to commercial viability.

The P & W division has three sources of revenue. The first is from the initial sale of the engine for application in airplane families like the Boeing 747 or the Airbus 320 or military jets. An engine can cost several hundred thousand, depending on size, type and a variety of other factors. Some engines like the JT8D have been in service for over three decades, while the PW6000 just entered into service near the end of 2005. The second revenue source is the engine overhaul and component repair services that take place with these expensive assets. This revenue source is relatively small. A third source of significant revenue is the after-market support from replacement part sales used in overhauls and repairs. This third multi-billion dollar revenue source for P&W is known as the 'spares' business.

A JET ENGINE

An aircraft moves through the air by generating a force called thrust from an engine. The most commonly used engines for large aircraft are gas turbine engines, also known as jet engines. All of P & W's engines are jet engines. Although jet engines come in various shapes and sizes, depending on the mission of the aircraft, all jet engines work using the same principles. A jet engine has four major components: a series of compressors, a combustion chamber, several turbines, and an exhaust nozzle. See Figure 1 for a typical engine diagram. Some jet engines, mainly the ones for large commercial aircraft, also have a fan that reduces the noise level. If an engine has a fan, it is called a turbofan. Otherwise, it is called a turbojet. Turbojets are primary used in military aircraft.

At the front of a jet engine is the inlet, which brings outside air into the engine. The inlet is part of the airframe and differs from aircraft to aircraft. For a turbofan engine, air is sucked into a large inlet by a rotating fan. At the end of the inlet are several compressors. A shaft to the turbines connects the compressors. The compressors and the turbines are composed of many rows of small airfoil shaped blades. Some rows are connected to the inner shaft and rotate at high speed, while other rows remain stationary. The rows that spin are called rotors and the fixed rows are called stators. The combination of the shaft, compressor and turbine is called the turbo-machinery. Between the compressor and the turbine flow path is the combustion chamber.

Most of the intake air bypasses the engine core and is forced out at lower velocities. The remaining air is compressed to a very high pressure, mixed with fuel, and ignited in the combustion chamber. The heated gas expands through the turbines that rotate the shaft and then is forced out the rear of the engine at a very high velocity through the smaller exhaust nozzle at an accelerated rate to create thrust. The nozzle performs two important tasks. The nozzle is shaped to accelerate the hot exhaust gas and is also used to set the mass flow rate through the engine. The expanding airstreams provide the thrust for the aircraft.

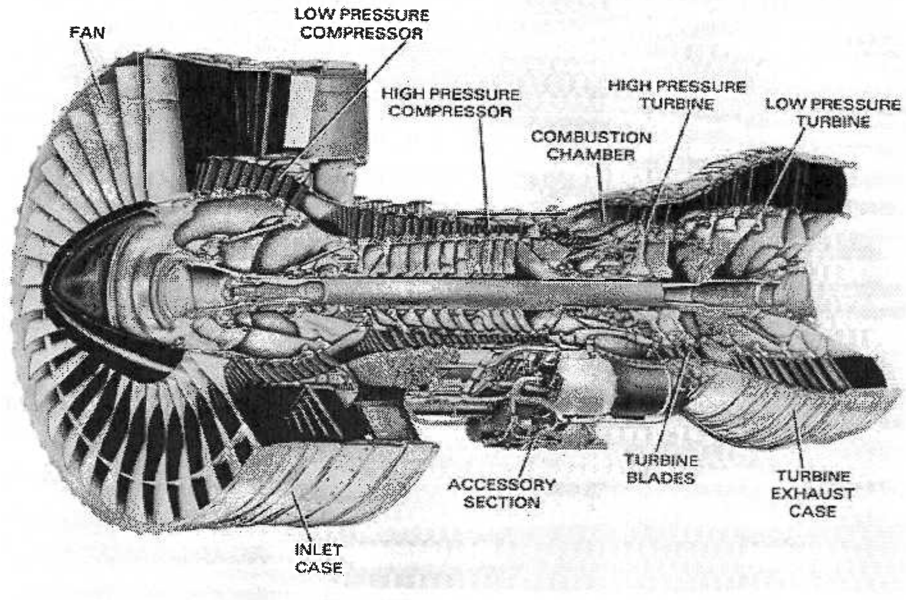

Figure 1: PW4000 Turbojet Engine

ENGINE PERFORMANCE

Each aircraft has a unique mission and therefore requires a certain type of propulsion system, and thus a unique type of engine. Commercial aircraft carry loads of passengers and/or cargo over long distances at a high speed. They spend most of their life in high cruise speed. The major stress on engines for these aircraft comes at take-off and landing. Fighter planes, on the other hand, have a different mission. Their mission is to engage in air-to-air combat. While they also spend most of their life in cruise speed, fighter planes need high acceleration when in combat or training for combat. High acceleration is generally unscheduled. In addition to take-offs and landings, high acceleration causes major stress on engines for fighter aircraft.

Stress on engines is measured by a metric called "cycles." The number of cycles is the measure used to make many maintenance decisions. Cycles are computed based on the number of take-offs, the number of landings and the accelerations an engine experiences. In commercial engines, the number of cycles is relatively easy to determine since it is directly related to the number of take-offs and landings. Commercial engines rarely go through any unplanned acceleration, compared to military engines. Therefore, the maintenance for military engines is much harder to predict and schedule. This clearly has implications for their spares planning decisions.

JET ENGINE PARTS

A jet engine is a complex piece of machinery with numerous parts, many of which spin on the shaft. Both the compressors and the turbines are composed of many airfoil shaped blades, which are constantly subject to high pressure gases at extreme temperatures. For example, as the air moves through the compressors, its pressure will increase by as much as 40 times and the temperature will rise dramatically. Combustion in the combustion chamber increases the temperatures and the gas velocities even further. The speeding gases that exit the combustion chamber then exert very high forces against the turbine blades. Turbine blades exist in a much more hostile environment than compressor blades because of these velocities and temperatures. Both compressor and turbine blades are parts that are replaced often in a jet engine because of the stresses of high pressure and temperatures.

Jet engine parts can cost anywhere from a few dollars to several hundred thousand dollars. The parts that cost more than a hundred thousand dollars tend to be one-off items such as casings. High volume items include such items as bolts and nuts, and also such specialized items as compressor and turbine blades. Table 1 illustrates a sample of spare parts and lists their value (please note that the cost figures have been modified to maintain confidentiality) and lead-time. Standard parts like bolts and nuts cost a dollar or so, whereas specialized items such as compressors and turbine blades can cost between $60 and $2000, depending on the type of blade and type of engine. Parts are purchased from both internal and external sources, with the majority of parts coming from external vendors. The lead times for most parts are upwards of 60 days, with some being as high as 270 days. With these long lead times, planning becomes very critical for the short delivery times and the high service levels that P&W promises its customers.

PARTS MANUFACTURING

P&W uses both division manufacturing facilities and hundreds of vendors to provide the thousands of items used in an engine. Because of the engine's hostile environment and stresses placed upon components, the production process is very demanding. For example, the manufacturing of turbine blades and vanes is a fairly complex process. These components are made of advanced materials that need to withstand extreme stresses and temperatures and meet stringent performance requirements set by engine designers and the Federal Aviation Administration.

Let us look at the production of jet engine vanes, which start as alloy castings received from outside suppliers. The production process, diagramed in Figure 2, begins with dot-peening or engraving of the unique identification number at the end of each vane. The vanes are then moved to a grinding operation, where radial grooves are cut along the sides of the vanes to facilitate their positioning in an engine ring and a hole is drilled into each vane for bolting into the engine. Vanes are then transported to an electrical discharge machining (EDM) operation where electrical arcs from graphite electrodes create slots into which seals will be placed during engine assembly to prevent air leakage inside the engine. The vanes are then washed before further processing to remove foreign material and particulate.

Material	Description	Cost Estimate**	Lead Time (days)	Model Name
PWA0001	STIFFENER-CYLINDER FINS	$1.06	70	JT8D
PWA0002	NUT OPTION (IC)	$15.17	60	PW2000
PWA0003	BLADE-HPC,11STG	$122.71	60	PW2000
PWA0004	BLADE-HPC,12STG	$126.69	60	PW2000
PWA0005	BLADE-HPC,12STG	$129.51	60	PW2000
PWA0006	BLADE-HPC,13STG	$131.52	60	PW2000
PWA0007	BLADE-HPC,14STG	$121.24	60	PW2000
PWA0008	BLADE-HPC,15STG	$139.73	60	PW2000
PWA0009	BLADE-HPC,15STG	$126.63	60	PW2000
PWA0010	BLADE-HPC,7STG	$199.75	60	PW2000
PWA0011	BLADE-HPC,9STG	$174.15	60	PW2000
PWA0012	RING SEG&VANE ASSY OF-HPT,2STG	$7,404.67	20	PW2000
PWA0013	BLADE ASSY OF-TURBINE ROTOR,1STAGE	$3,186.82	40	PW2000
PWA0014	SEAL-PLAIN,5.080X.150X.155	$123.25	70	V2500
PWA0015	SEAL-PLAIN,6.572X.226X.212	$570.53	76	V2500
PWA0016	BLADE-HPT,1STAGE	$2,828.73	162	V2500 A1
PWA0017	BLADE ASSY OF-HPT,2STAGE	$2,075.25	147	V2500 A1
PWA0018	SUPPORT-NOZZLE STATOR GUIDE	$333.65	230	JT9D
PWA0019	WASHER-SHOULDERED,.258X.852	$9.91	90	PW4000
PWA0020	BEARING OPTION (IC)	$12,563.55	195	PW4000
PWA0021	PLUG-MACH THD,.5625-18X.400,SOCKET	$56.44	5	JT8D
PWA0022	BEARING OPTION (IC)	$27,435.16	275	PW4000
PWA0023	BEARING	$44.46	120	PW4000
PWA0024	CHANNEL-GANG NUT,DIFSR,ASSY OF	$265.94	10	JT8D
PWA0025	DUCT SEGMENT-HPT,1STG	$1,805.88	60	PW4000
PWA0026	DUCT SEGMENT-HPT,2STG	$1,821.30	95	PW4000

Table 1: Sample Spare Parts at Pratt & Whitney Commercial Aviation
(**Note: the cost figures have been modified to maintain confidentiality.)

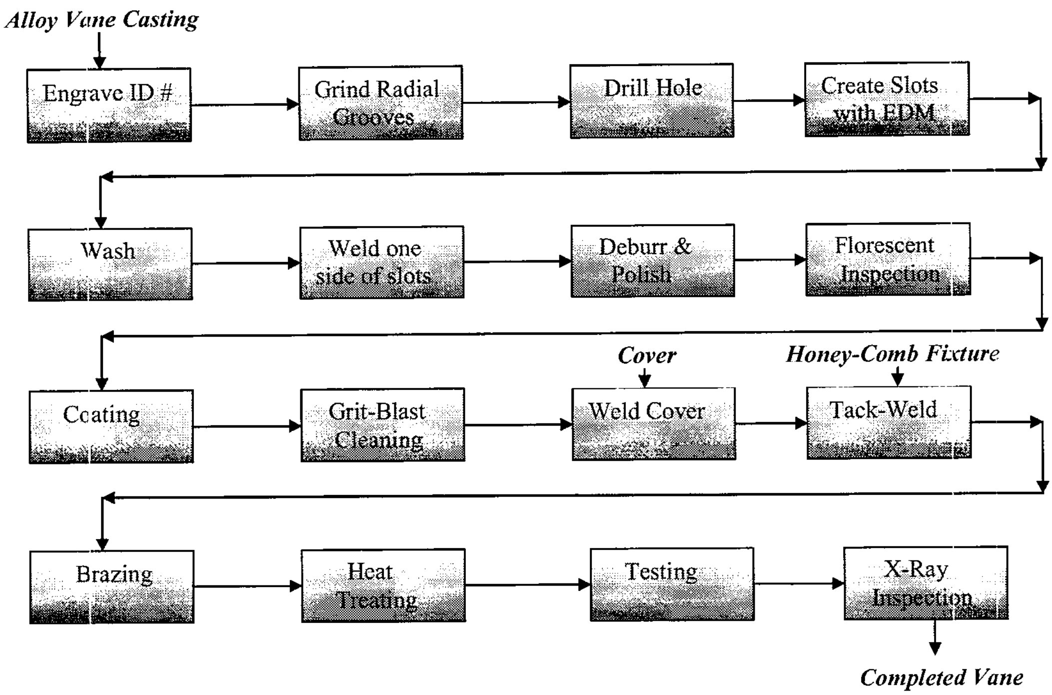

Figure 2: Valve Production Process Map

In another operation, the electrical discharge machining slots are welded closed on one side in order to secure the seals. From there the vanes pass to the next workstation to be deburred and polished in a vibrating bowl filled with the polishing media. In a separate operation, each vane is then analyzed with a florescent penetrate inspection process to detect cracks, voids, or other defects. After this inspection, the vanes are further analyzed and sent to a coating area to be plasma-sprayed with a metallic and ceramic overlay coating to increase durability.

Next, the vanes go to a grit blast work center for cleaning and then to a welding operation. There, a cover is affixed to the vane to create a channel through which air passes inside the vane to cool the engine's inner seal. Metal honey-comb fixtures are then tack-welded to the vane to create an additional seal in a brazing operation. The brazing operation is completed inside a high-temperate vacuum furnace. A twelve-hour pressurized heat-treating process follows, which stabilizes the various metallic components to form a stronger structure. Vanes are then tested using water-flow and air-flow tests. Finally, the vanes are x-rayed to detect foreign material inside the vane. Completed vanes are then sent to assembly operations or placed in stock.

The production of vanes, as well as blades, utilizes equipment that costs many millions of dollars. The electric discharge machining and grinding processes, in particular, are designed to maintain specified tolerances at a very high level of accuracy. Most of this equipment is computer-controlled, like the computer-controlled 12-axis blade grinding machines employed for the shaping of blades so that they will snap firmly into the turbine disks.

SPARES DEMAND PLANNING

The starting point for spares management is the demand planning/forecasting function. With 22,000 items to plan on a routine basis, this is a major task. While many parts are manually forecasted because of very low demand or extremely expensive part cost, the commercial spares group utilized a time series approach for forecasting about 15,000 of its spare parts. The past approach used a moving average model with a six to twelve month base to predict the next three to four months. However, the recent installation of SAP's Advance Planning Optimizer (APO) software system has created an opportunity. This system contains thirty-six different forecasting tools for modeling time series. The question now before the spares planning management is; 'Which forecasting models are appropriate for estimating future demand for the thousands of spare items carried in stock?' The patterns of demand history for spare parts show significant differences, which could influence predictability and model performance. For example, Figure 3 graphs four different spare part time series for a 70-month horizon. Note the volatility of demand from month to month, the presence of trends and the absence of demand in some periods.

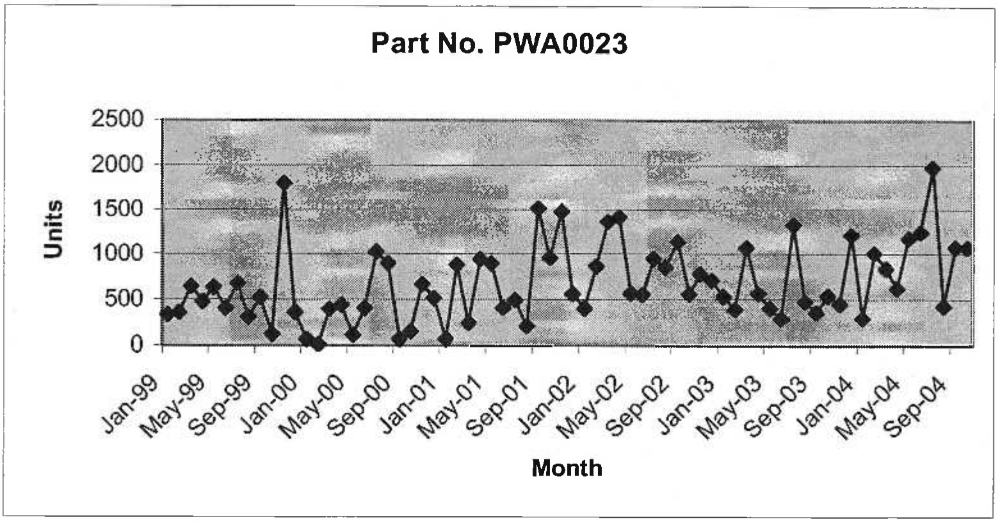

Figure 3: Spares Sample Time Series

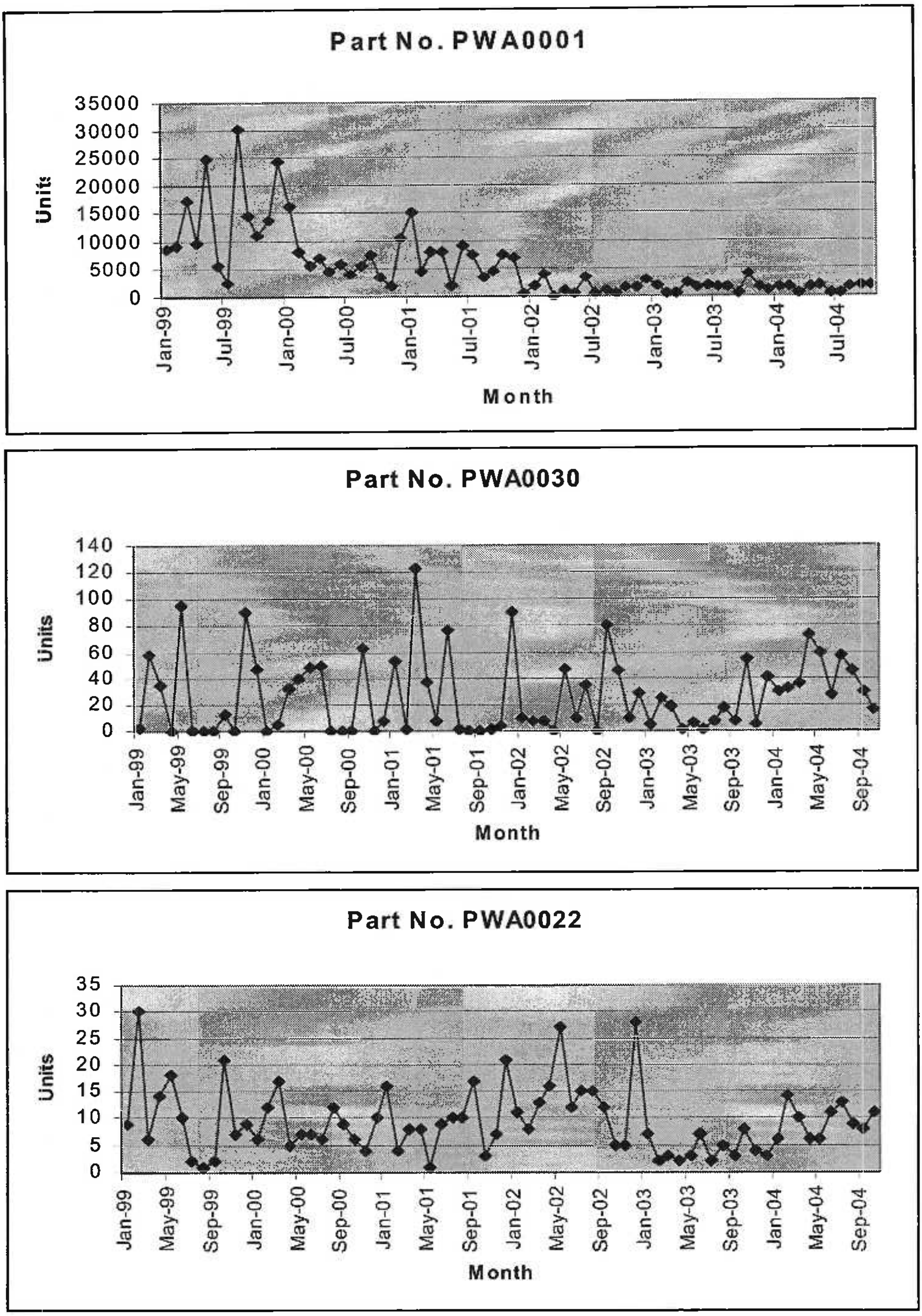

Figure 3: Spares Sample Time Series (continued)

As a starting point in evaluating what models might be the most appropriate, a subset of eight APO forecasting models have been targeted for review. These forecasting models are shown in Table 2.

Constant	Simple Exponential Smoothing
Moving Average	Exponential Smoothing with Trend
Simple Regression	Exponential Smoothing with Seasonality
Croston's Model	Exponential Smoothing with Trend & Seasonality

Table 2: Forecasting Models Included in the DSS

To assist in this review, a decision support system (DSS) was developed with the eight models and the typical forecast features in the APO software (note: a copy of this Excel-based DSS is available from the authors upon request[2]). This DSS would allow an evaluation of different system features without interfering with routine business planning on the SAP APO system. The DSS features included the following:

- Forecast horizons chosen by the user.
- Option of having model coefficients selected by the user or optimized by the DSS.
- Multiple error performance measures calculated.
- Automated model initialization.
- Ability to evaluate several different models simultaneously within a single spreadsheet workbook.

The DSS also contains a sample of 65 representative spare items, each having a 70-month demand history that can be used for testing and evaluating the different forecast models.

Of the forecasting models included in the DSS and shown in Table 2, the "Constant" model is the simplest – it uses a single constant value to forecast demand for all future periods. "Croston's Model" (Croston, 1972), which is perhaps the least well-known of the eight models, was developed especially for forecasting items that tend to have intermittent demands. The other forecasting methods, which include "Moving Average," "Simple Regression," and various forms of exponential smoothing, are well-known methods. Descriptions of these and other forecasting models can be found in Makridakis et al. (1998) and Yurkeiwicz (2004).

The issue now before the spares planners of John Doyle, Greg Campagnano and Larry Hosey is: "How should the evaluation be conducted?" To demonstrate the application of the DSS, Figure 4 illustrates an example of how the DSS can be used to evaluate a forecasting model. The screen shot in Figure 4 shows the results of applying simple exponential smoothing with an alpha of 0.3 to the demand steam for part number PA0023, which is the first sample time series shown in Figure 3. Figure 4 highlights some of the decisions that need to be made in the course of conducting an evaluation, including choices of forecasting intervals and which performance measures to use for choosing amongst alternative methods. Although tools such as the Excel-based DSS illustrated in Figure 4 can facilitate evaluations, forecasting model selection remains a complex problem for demand planners at Pratt and Whitney Aircraft.

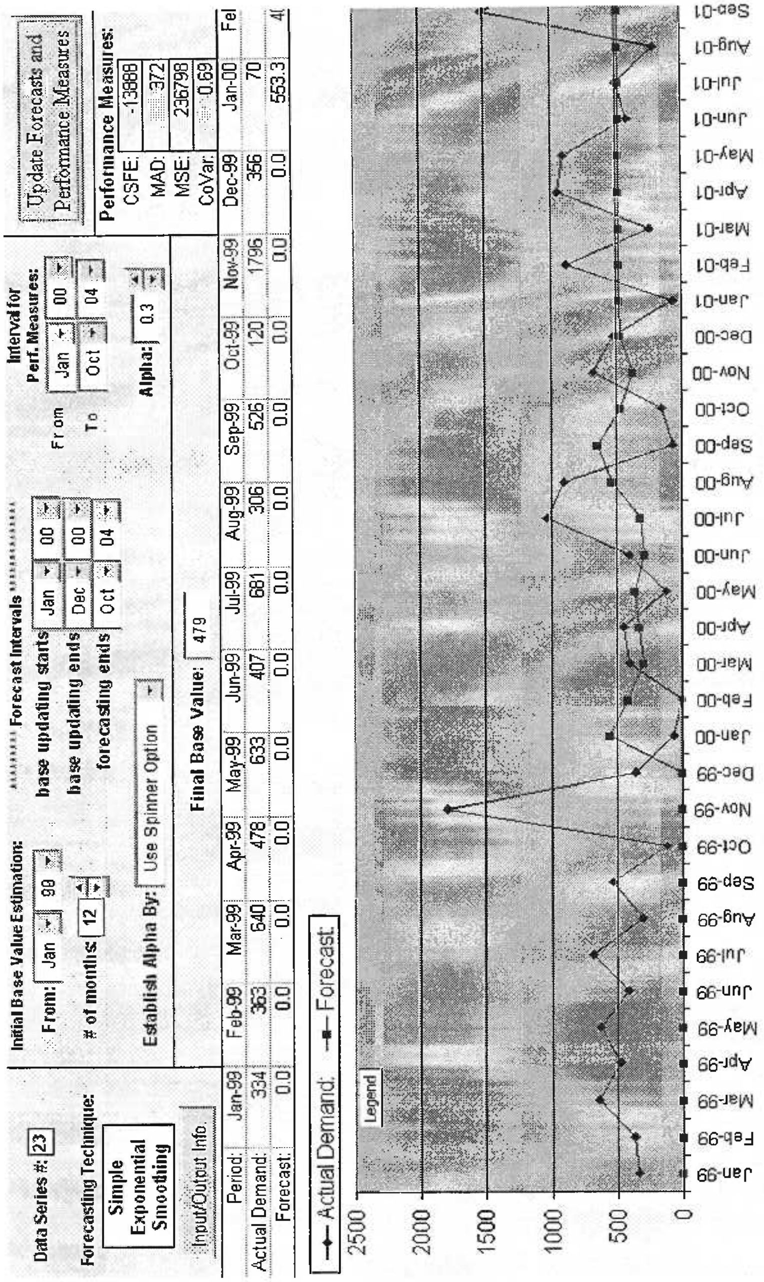

Figure 4: Example of Evaluating a Forecasting Model with the DSS

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ENDNOTES

[1] The authors wish to express their appreciation to Pratt & Whitney management and staff for their assistance in the preparation of this case study. Operational and financial data have been disguised to maintain confidentiality.

[2] The Excel-based DSS, which is available from the authors upon request, includes documentation and instructions to facilitate evaluation of alternative forecasting models for the 65 demand streams contained within the DSS.