

**Redefining the Aftermarket Demand Forecasting Process Using Enterprise  
Resource Planning**

by

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Bachelor of Science in Mechanical Engineering  
United States Military Academy, 1993

Submitted to the Department of Mechanical Engineering and the Sloan School of  
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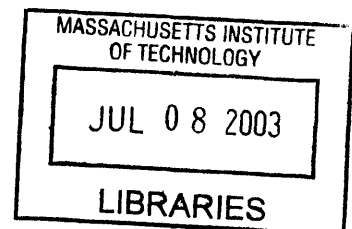
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**BARKER**





# **Redefining the Aftermarket Demand Forecasting Process Using Enterprise Resource Planning**

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## **ABSTRACT**

The work for this thesis was performed at Pratt & Whitney, a leader in the design, production, and support of engines for commercial, military, and general aviation aircraft. Specifically, the project focused on developing a process to generate a part-type demand forecast for all Pratt & Whitney Commercial Aftermarket repair facilities worldwide using historical Enterprise Resource Planning (ERP) data.

The author worked as part of a demand planning team to develop Phase 1 of the Aftermarket Demand Planning Process (ADPP). The ADPP converts an engine shop visit forecast into a part-type Aftermarket demand forecast using historical demand trends identified in the ERP transactional data. As part of the demand planning team, the author analyzed the shortcomings in the existing forecasting process, identified the information requirements of the potential end users, and analyzed the content and format of transactional data in Pratt ERP systems. The demand planning team also developed data-mining, cleansing, and processing logic to extract ERP data that is useful in analyzing historical demand patterns and in predicting future demand patterns.

The result is a successful Phase 1 implementation of the ADPP and a continuing acceptance of the process in the overall Pratt & Whitney business process.

Thesis Advisor: David E. Hardt, Professor of Mechanical Engineering

Thesis Advisor: Roy E. Welsch, Professor of Statistics and Management Science

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## 1 Chapter 1. Introduction

This chapter introduces the objectives, the problem overview, and the overall structure of this thesis.

### 1.1 Thesis Objectives

This thesis is the outcome of a joint effort between the MIT Leaders for Manufacturing program and Pratt & Whitney, a division of United Technologies Corporation. The concept formulation, research, and project execution for this thesis were performed between June, 2002 and January, 2003 at the Pratt & Whitney facility in East Hartford, Connecticut. The objective of this project is to develop and implement Phase 1 of the **Aftermarket Demand Planning Process (ADPP)**. The ADPP is a forecasting process that utilizes historical operational data from Enterprise Resource Planning (ERP) systems operated by Pratt & Whitney Commercial Aftermarket repair facilities. Specifically, this project includes the concept formulation of the ADPP, the development of ERP data-mining, data-cleansing, and data-aggregation logic, the analysis of historical Commercial Aftermarket demand data, and the development of a process that utilizes historical demand patterns in the ERP data to convert an engine shop visit forecast into a part-type demand forecast.

### 1.2 Problem Overview

*Forecasting is always difficult, especially with regard to the future.<sup>1</sup>*

- Victor Borge

Pratt & Whitney Aftermarket Services (Commercial Engines) manages all Pratt & Whitney commercial aircraft engine repair operations worldwide. Currently, **Pratt & Whitney Aftermarket Services (PWAS)** has an insufficient process for accurately forecasting part-type demand for its engine overhaul centers and part repair facilities.

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<sup>1</sup> Victor Borge, as quoted by Robert C. Higgins. *Analysis for Financial Management*. 6<sup>th</sup> Ed. (New York: Irwin/McGraw-Hill, 2001); 86.

Aftermarket repair facilities receive an annual demand forecast from the Sales and Marketing organization at Pratt. The current Sales forecasting process is cumbersome, non-standardized, and focused on generating financial forecasts rather than on generating accurate operational forecasts. The primary outputs of the annual Sales forecasting process for PWAS are annual sales revenue forecasts, in dollars, that are subsequently converted into Aftermarket operational forecasts, which include information such as repair services and replacement volumes for specific engines and parts. The method used to convert the annual sales revenue forecasts into Aftermarket operational forecasts neglects certain intricacies of Aftermarket operations, which introduces significant uncertainty into the operational forecast. The non-standardized process for generating annual sales revenue forecasts, combined with an inadequate conversion process, results in operational forecasts that lack sufficient and reliable operational details necessary for Aftermarket managers to optimize their operations.

As a result, Aftermarket demand is considered highly variable and uncertain, which leads to increased inventory, costs, service lead times, and other effects due to mismatched capacity and demand. Although the financial forecasts are accurate, the Sales and Marketing organization realizes the problems inherent in translating financial forecasts into operational forecasts, and is actively seeking solutions in conjunction with PWAS. This project involves one such solution, the ADPP, which is a data-based, standardized, and highly-automated process to forecast global part repair and scrap replacement demand. The intent of the ADPP is to provide Aftermarket managers with the operational forecasts they require to optimize their operations. The Aftermarket demand planning team also intends to work with Sales and Marketing managers to incorporate the ADPP into the official Sales and Marketing forecasting process.

### **1.3 Thesis Structure and Overview**

This thesis represents the culmination of the author's work and research as a member of the Aftermarket demand planning team at PWAS. The structure of this thesis is designed to introduce the intricacies of the Aftermarket business at Pratt & Whitney, followed by an analysis of the problems inherent in the current Sales forecasting process from an

operational perspective. The author will then introduce the conceptual basis for the ADPP, followed by a detailed description of the development and implementation of Phase 1. The ADPP project goals, objectives and deliverables for Phase 2 and Phase 3 are also introduced. The thesis concludes with an analysis of the future development efforts and implementation of the ADPP at Pratt & Whitney, including the incorporation of the ADPP into the official Sales forecasting process and into other important initiatives.

The structure of the thesis is as follows:

Chapter 2 provides a brief analysis of the Aftermarket business at Pratt & Whitney, and introduces key terminology and operational characteristics of Aftermarket repair facilities that are referenced throughout the thesis. Also, the intricacies of Aftermarket demand are also introduced.

Chapter 3 briefly describes the current Sales forecasting process as it pertains to PWAS, and analyzes the resulting forecast that is generated for Aftermarket repair facilities.

Chapter 4 introduces the conceptual basis for the ADPP, and describes the value of accurate Aftermarket operational forecasts for Pratt & Whitney. The goals, objectives, and deliverables for all phases of the ADPP are also discussed, as well as the ERP data-mining approach.

Chapter 5 describes the data-aggregation strategies employed by the demand planning team to effectively analyze large amounts of ERP data and to identify historical demand trends in the data.

Chapter 6 describes the conceptual basis and process for constructing static and dynamic engine templates. Complete engine templates are the cornerstone of the ADPP, and operate as **Typical Engine Part Disposition (TEPD)** profiles that are used to convert

engine shop visit forecasts into a part-type demand forecast. Also, the ERP data-cleansing logic employed by the demand planning team is also introduced.

Chapter 7 describes the actual process of using TEPD profiles to generate global Aftermarket demand forecasts.

Chapter 8 analyzes the future evolution of the ADPP, including the incorporation of the ADPP into the Sales and Marketing forecasting process and in other initiatives.

## **2 Chapter 2. Pratt & Whitney Aftermarket Services (Commercial Aircraft Engines)**

This chapter focuses on the products, services, terminology, and demand complexity that are inherent in the Commercial Aftermarket business at Pratt & Whitney.

### **2.1 Pratt & Whitney Organizational Overview**

Pratt & Whitney is a division of **United Technologies Corporation (UTC)**. Other major divisions of UTC include Sikorsky Helicopters, Otis elevators and escalators, Carrier heating and air conditioning, systems, and Hamilton Sundstrand aerospace systems.<sup>2</sup>

The organizational structure of Pratt & Whitney resembles the hierarchical structure of a traditional mass-producer, with major business units organized by function (e.g. Finance, Sales and Marketing, Human Resources) or by major product line. The four major product groups are:

1. Commercial Aviation - including large commercial aircraft engines and Pratt & Whitney Canada (small) engines.
2. Military Aviation
3. Space & Missile Propulsion
4. Power Systems & Mechanical Drive

The scope of this thesis is limited to the Aftermarket Services division for Commercial Aviation.

### **2.2 Pratt & Whitney Aftermarket Services Overview**

Pratt & Whitney Aftermarket Services, Commercial Engines (PWAS) is responsible for all Aftermarket service and support activities associated with Pratt & Whitney Commercial Aircraft Engines. These activities include Aftermarket maintenance, Spare Parts, customer service, and customer training. The customers of Pratt & Whitney

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<sup>2</sup> *Pratt & Whitney Company Profile* (accessed April 5, 2003); available from <http://www.pratt-whitney.com/>

Commercial Engines include almost every major airline. As the Pratt & Whitney website states:

“More than 600 airlines operate with Pratt & Whitney large commercial engines in more than 150 countries... Today, Pratt & Whitney engines power more than half of the world's commercial fleet. Every few seconds – more than 20,000 times a day – a Pratt & Whitney-powered airliner takes flight somewhere in the world.”<sup>3</sup>

The scope of this thesis focuses on the Aftermarket maintenance operations and the Spare parts organization for large commercial engines.

### **2.3 PWAS Engine Centers and Part Repair Facilities**

Aftermarket maintenance operations are performed by Pratt & Whitney Engine Overhaul Centers and Part (or “Component”) Repair Facilities. Pratt has five primary Commercial Engine Overhaul Centers<sup>4</sup>, or Engine Centers, and approximately 25 part repair facilities located around the world. The map on the next page depicts the locations of some of these facilities.

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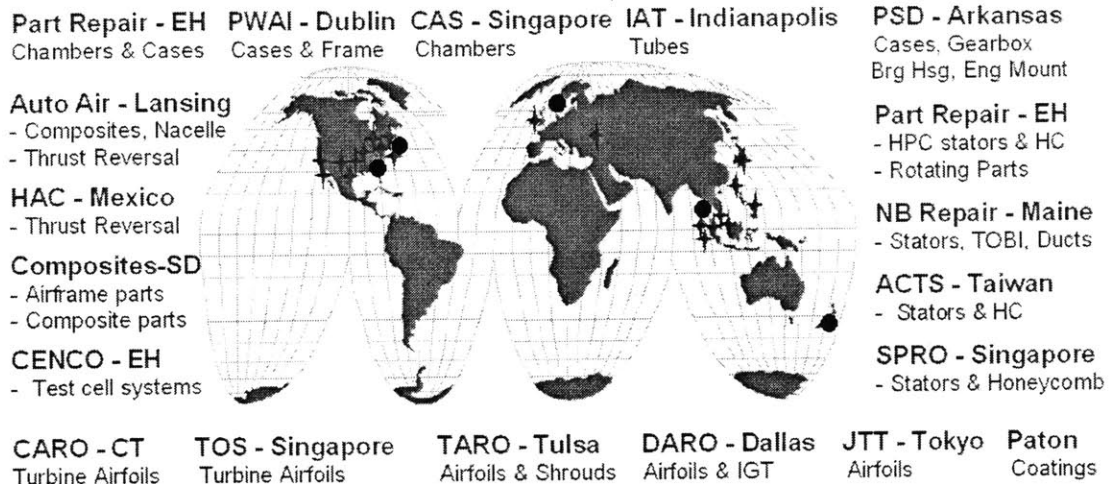
<sup>3</sup> *Pratt & Whitney Company Profile* (accessed March 30, 2003); available from <http://www.pratt-whitney.com/>

<sup>4</sup> Pratt operates an Engine Test facility in Middletown, CT that can also perform engine overhauls as needed. However, it is not considered one of the five dedicated Engine Centers in this thesis.



# PW Aftermarket Services

## Global Parts Repair & Services



## Engine Service Centers

Norway	Singapore	San Antonio	Columbus	Christchurch	Cheshire
CFM56-3	PW4000	F100	JT8D-Std	JT8D-Std	PW4000
CFM56-7	JT9D	(Military)	JT8D-200	RR Dart	PW2000
CFM56-5	CFM56		V2500	V2500	JT9D

Figure 2.1. Pratt & Whitney Aftermarket Facilities and Locations.<sup>5</sup>

### 2.3.1 Commercial Engine Centers

The five commercial Engine Centers service all Pratt & Whitney engines as well as certain engines produced by competitors. As depicted in Figure 2.1, the five Commercial Engine Centers are located in Norway, Singapore, Columbus (Georgia), Christchurch (New Zealand), and Cheshire (Connecticut). The five Pratt & Whitney Engine Centers perform a total of approximately 800 engine overhauls in an average year.

The Engine Centers serve as the system integrators for the entire engine overhaul process. The Engine Centers receive, or “induct”, engines from the customer, disassemble and inspect each part, and determine the appropriate service that will be performed on each part. Also, the Engine Center will determine where the part will receive service and will

<sup>5</sup> Pratt & Whitney Map (accessed March 27, 2003); available from [http://pwww.eh.pweh.com/pwes/map\\_as.html](http://pwww.eh.pweh.com/pwes/map_as.html)

track the progress of each part as it moves through the overhaul process. The Engine Center will then collect repaired or replaced parts, re-assemble the engine, test the engine, and ship it to the customer. The role of the system integrator in the engine overhaul process is extremely complex, as each engine consists of over 4500 individual parts, and a complete engine overhaul is completed in approximately 60-90 days. The complexities inherent in the Aftermarket business are examined in later sections of this chapter.

Of central importance to the work supporting this thesis is the fact that Engine Centers also manage and record the flow of information that corresponds to the physical flow of parts throughout the engine overhaul process. The Engine Centers are responsible for tracking, recording, and verifying all the transactional data associated with the entire engine overhaul process. This data is currently recorded in **Enterprise Resource Planning (ERP)** systems utilized by the Engine Centers. The demand planning team uses this data as the basis for the Aftermarket Demand Planning Process, which is a process that is discussed in detail throughout this thesis.

Engine Centers can also perform certain part repair operations in-house, or they can opt to ship the parts to a part repair facility due to capacity or time constraints.

### **2.3.2 Part Repair Facilities**

Part repair facilities receive and repair parts from Pratt Engine Centers, as well as parts from external engine overhaul facilities. External engine overhaul facilities include engine overhaul facilities operated by competing aircraft engine manufacturers or engine overhaul facilities operated by major airlines, such as Delta Airlines or United Airlines.

Part repair facilities typically repair a specific set of parts from a wide variety of engines. For example, a part repair facility may only repair turbine blades and vanes from a specific set of engine models, while another part repair facility may only repair combustion chambers and large rotating parts.

All Pratt part repair facilities are in the process of implementing ERP, which will continue through 2005.

### **2.3.3 Pratt & Whitney Spares Organization**

The Spares organization is responsible for managing all new and used spare parts. The Spares organization replaces scrapped parts with new (OEM) parts when a part is scrapped at a Pratt repair facility or at an external repair facility. Spares typically replaces parts on a part-serial-number-for-part-serial-number basis, meaning that a replacement part is exactly the exact same version and derivative as a scrapped part.

The part-number-for-part-number aspect of the spare parts business illustrates an important difference in the operational dynamics of the Spares organization as compared to the Aftermarket repair facilities. Part repair facilities repair groups of parts that perform similar functions within an engine and, more importantly, groups of parts that are repaired using similar processes. Therefore, unlike Spares, a part repair facility is less concerned with individual part numbers and more concerned with groups of parts from different engines that perform the same basic function and are repaired using the same repair lines and processes. This difference in operational dynamics results in different information requirements between the two organizations, specifically from a demand forecasting perspective. The differences in information requirements among potential end users of the ADPP are a central concern of the demand planning team, and will be addressed further throughout this thesis.

### **2.3.4 Enterprise Resource Planning (ERP).**

Pratt & Whitney Aftermarket repair facilities are in the process of implementing ERP across all Engine Centers and part repair facilities. At the time this thesis is written, all five Engine Centers have implemented ERP, while the ERP implementation for part repair facilities will continue through 2005.

Daniel O' Leary, in his book "Enterprise Resource Planning Systems," describes ERP as:

... computer-based systems designed to process an organization's transactions and facilitate integrated and real-time planning, production, and customer response...ERP systems integrate the majority of a business's processes...[and uses] an enterprise-wide database that typically stores each piece of data once...[while allowing] access to the data in real time.<sup>6</sup>

For the purposes of the Aftermarket Demand Planning Process (ADPP), ERP systems provide a comprehensive data source for all historical Aftermarket demand transactions. Also, ERP provides a framework for standardizing data and business processes across Pratt & Whitney Aftermarket Services. The data stored in the Aftermarket ERP systems represents *the actual demand history of a repair facility*, and provides the basis for the ADPP as discussed in Section 4.6 of this thesis.

## **2.4 Aftermarket Terminology**

This section introduces some terminology that is used throughout this thesis.

### **2.4.1 Engine Family, Engine Model, and Engine Thrust Code**

Pratt & Whitney classifies its large commercial aircraft engines hierarchically by Engine Family, Engine Model, Engine Thrust Code, and Engine Serial Number. This natural hierarchy is utilized by the ADPP to aggregate engines with similar engine configurations and to generate demand forecasts.

The **Engine Family** is the highest level in the hierarchy. An engine family represents a major product offering with a broad range of engine thrust capabilities for a broad set of aircraft types and customers. Engine families are designed to satisfy the strategic needs of the customer, including specific design requirements that are based upon aircraft weight, distance traveled, and other needs of the customer. Engine families are often categorized by the pounds of takeoff thrust they produce and by the types of aircraft they

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<sup>6</sup>Daniel E. O' Leary, *Enterprise Resource Planning Systems: Systems, Life Cycles, Electronic Commerce, and Risk* (Cambridge, UK: Cambridge University Press, 2000), 27.

are intended to power. A decision to design and develop a new engine family represents a significant strategic and financial commitment by Pratt & Whitney. The life cycle of an engine family is approximately 20-30 years. There are seven Pratt & Whitney large commercial engine families, in various stages of their individual life cycles, currently operating in the world.<sup>7</sup>

An **Engine Model** represents a distinct group of engines within an engine family that share a narrower range of takeoff thrust capabilities, engine configurations, and intended customers and aircraft types.

An **Engine Thrust Code** represents a distinct group of engines within an engine model grouping that share a very small range of takeoff thrust capabilities and engine configurations. Engine thrust codes are customer specific, and therefore can be tailored to fulfill the needs of the customer and the aircraft for which the engine will power. For example, due to slight differences in the instrumentation packages and in aircraft design, an engine will interface with an Airbus commercial jet differently than it will interface with a Boeing commercial jet. The different external interfaces of engines, including differences in the way the engines are mounted on the aircraft, are captured in the engine thrust code.

An **Engine Serial Number** is a unique identification number used to identify and track a single engine. From an engine serial number, one can determine important information about the engine such as its engine thrust code, engine model, and engine family.

#### **2.4.2 Part Disposition Codes**

The ADPP utilizes specific historical information in the Pratt ERP databases in order to generate demand forecasts. **Part disposition codes** represent a specific set of historical ERP data that is of central importance to the ADPP.

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<sup>7</sup> *Pratt & Whitney Products* (accessed April 1<sup>st</sup>, 2003); available from <http://www.pratt-whitney.com/>

When an engine is inducted into an Engine Center for overhaul, the engine is disassembled and parts are inspected in order to determine the level of service that each part will require. Any part that is inspected can receive one of three primary disposition codes:

1. **Serviceable.** Part does not require service and can be put back on the engine “as-is.”
2. **Repair.** Part requires a repair process that can be accomplished either at an Engine Center or at a part repair facility.
3. **Scrap.** Condition of the part exceeds the allowable limits for repair and must be discarded and replaced by a new (OEM) part.

For a part that requires repair, the Engine Center will determine if the part will be repaired internally at the Engine Center, or if the part will be shipped to an external Pratt & Whitney part repair facility. Part repair facilities perform a separate inspection on the parts they receive from the Engine Center, and can disposition a part as repair or scrap.

The disposition of a part, as well as the internal or external source of a part disposition, is recorded in ERP by part serial number. ERP utilizes **part disposition codes** to reflect this information succinctly. The following is a list of the five ERP part disposition codes that the demand planning team utilizes in Phase 1 of the ADPP:

- S:** Serviceable. Part can be placed back on the engine in its current condition.
- I:** Internal Repair. Part requires repair that is performed by the inspecting Engine Overhaul Center.
- E:** External Repair. Part requires repair that is performed by an external Pratt & Whitney part repair facility.
- Rb:** Scrap at Engine Center. Part is scrapped based upon the inspection at the Engine Center, and will therefore require a new replacement part.
- Rv:** Scrap at External Vendor. Part is scrapped based upon the inspection at the external Pratt & Whitney part repair facility, and will therefore require a new replacement part.

### 2.4.3 Engine Module, Workscope, and Engine Shop Visit

An **engine module** is a major section of an engine, which typically performs a major function within an engine. The five primary engine modules on a turbofan engine are the fan (intake) module, compression module, combustion module, turbine module, and exhaust module.<sup>8</sup>

The **workscope** is the level of service or repair that a product requires. The workscope of a product is directly related to the amount of labor and cost that Pratt invests in the repair or replacement of a product.

There are several workscope classifications used at Pratt. However, there are only three primary workscope classifications that pertain to the work completed for this thesis, which are **light, medium, and heavy**. A heavy workscope generates the highest cost of the three workscope classifications, and is also the most labor-intensive.

In the Pratt Aftermarket business, a workscope can be assigned to engines, engine modules, and parts. This thesis will focus on engine-level workscope and module-level workscope classifications.

An **engine shop visit** occurs when an engine is removed from a wing and sent to an Engine Center for overhaul.

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<sup>8</sup> United Technologies Corporation, *Pratt & Whitney Operating Instructions 200: The Aircraft Gas Turbine Engine and Its Operation* (Hartford, CT: United Technologies Corporation, 1988).

## 2.5 Overview of Engines for Phase 1

The five engine families that are the focus of Phase 1 are listed below. All the engines listed below are manufactured by Pratt & Whitney except for the CFM56. However, Pratt Engine Centers have the capability to overhaul CFM56 engines, so they represent a significant source of Aftermarket demand.

Engine Family	Engine Model (ADPP Phase 1)	Take-off Thrust (lbs)	Aircraft Powered	First Flight/Remarks
PW4000 <sup>9</sup>	94-inch	52,000 - 62,000	Boeing 747-400 Boeing 767-200/300 Boeing MD-11 Airbus A300-600 Airbus A310-300	Aug 1985  (Refer to Footnote 9)
	100-inch	68,000	Airbus A330-300 Airbus A330-200	Oct 1993  (Refer to Footnote 9)
	112-inch	86,760-90,000	Boeing 777-200/-300	Nov 1993  (Refer to Footnote 9)
PW2000	Commercial	37,000-43,000	Boeing 757	Oct 1984  (Refer to Footnote 9)
V2500	A1, A5	22,000-33,000	Airbus A319,A320,A321 Boeing MD-90	1989 (Refer to Footnote 9)
JT8D	200	21,000	Boeing 727 Boeing 737-100/-200 McDonnell Douglas DC-9 Boeing MD-80	Feb 1964  (Refer to Footnote 9)
CFM56 <sup>10</sup>	All	18,000-35,000	Airbus A318, A319, A320 Boeing 737-300/400/500	GE Engine (Refer to Footnote 10)

**Figure 2.1. Engine Families for Phase 1 of the ADPP.**

<sup>9</sup> *Pratt & Whitney Products* (accessed March 30, 2003); available from <http://www.pratt-whitney.com/>

<sup>10</sup> GE Aircraft Engines, CFM56 (accessed April 5, 2003); available from <http://www.cfm56.com/engines/stats.html>



## 2.6 The Demand Complexity of Aftermarket Services

The complexities inherent in forecasting Aftermarket demand far exceed the complexities of forecasting demand for new engines, which poses a major challenge to Aftermarket demand forecasting processes. **Original Equipment Manufacturing (OEM)** production involves relatively long design and test cycles, measured in years, and several years between new product offerings. OEM production managers and designers work closely with the major aircraft manufacturers to design engines that compliment the new aircraft designs. Major aircraft manufacturers perform detailed market analysis and demand forecasts for new and existing aircraft types, which Pratt & Whitney can use to determine OEM engine demand for those aircraft.

Furthermore, due to the length of time between product offerings, OEM forecasting can be limited to a single engine family or a single engine model, with a standard set of parts and engine configurations. OEM engine production processes can be standardized in order to mass-produce these standard sets of parts.

As a result, demand for new engines can be forecasted relatively accurately, including production schedules, delivery dates, and life cycle costs.

In contrast, Aftermarket demand is much more complex. Unlike OEM forecasting that focuses on single engine families or single engine models, Pratt & Whitney Aftermarket Services performs maintenance for seven engine families currently in operation, including all the engine models and engine thrust codes within the seven engine families.<sup>11</sup> As the P&W website claims, the number of Pratt & Whitney engines currently in service is significant:

*[Pratt engines in service number] about 18,000 commercial engines and nearly 11,000 military engines, supported by representatives in 76 cities in*

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<sup>11</sup> *Pratt & Whitney Products* (accessed April 1<sup>st</sup>, 2003); available from <http://www.pratt-whitney.com/>

*47 nations. In addition, about 33,000 Pratt & Whitney Canada engines are in service around the world.*<sup>12</sup>

Therefore, the demand generated by the Aftermarket business stems from a large and varied installed base.

Also, unlike the standardized production processes and standardized sets of parts inherent in OEM production, Aftermarket demand involves many different processes that service many different parts from different engine models that require varying levels of service. When an engine is inducted for overhaul, the engine is disassembled and every part is inspected to determine the level of service that each part will require. Any part that is inspected can receive one of three primary disposition codes: Serviceable, Repair, or Scrap, and one of five ERP part disposition codes.

A typical engine consists of approximately 4500 parts that vary significantly across engines within different engine families or within different engine models. Furthermore, each part can be repaired or replaced from several competing sources based upon the ERP part disposition code.

Also important in describing the complexity of Aftermarket demand is the fact that PWAS derives the majority of its annual demand from overhauls that are performed by external repair facilities (airlines that have internal engine shops and perform their own overhauls). The number of variables and considerations that affect Aftermarket demand far exceed the number of variables and considerations that affect OEM demand.

The demand complexity of the Aftermarket business makes Aftermarket demand forecasting exponentially more difficult than OEM demand forecasting. However, through the use of sophisticated information technology systems, and utilizing clever

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<sup>12</sup> *Pratt & Whitney Fast Facts* (accessed March 30, 2003); available from <http://www.pratt-whitney.com/>

data aggregation and cleansing techniques, the ADPP promises to account for this demand complexity and generate reliable Aftermarket demand forecasts.

## **2.7 Internal versus External Demand**

In order to fully understand the ADPP, one must understand the difference between internal and external demand from an Aftermarket perspective.

**Internal demand** is defined as the part-type demand that is created by engines overhauled by the five Pratt & Whitney Engine Centers.

**External demand** is defined as all the part-type demand that is generated from engines overhauled by all the non-Pratt & Whitney Engine Centers. Several major airlines, as well as competing aircraft engine manufacturers, have their own internal engine overhaul capabilities that can overhaul Pratt & Whitney engines. Similar to a Pratt & Whitney Engine Center, an external Engine Center will outsource certain part repair and part replacement operations to competing vendors. Pratt & Whitney Sales representatives compete for this available external market share for the outsourced part repair and part replacement contracts. As a result, parts from external Engine Centers are shipped to Pratt Aftermarket repair facilities for repair, and orders are placed with the Spares organization for replacement parts. External demand accounts for the majority of the total annual demand for PWAS in an average year.

External demand is much more complex and variable than internal demand for several reasons.

1. External demand accounts for a much larger piece of the total demand, and this demand is generated by as many as 20-30 external Engine Centers.
2. The market share that Pratt receives from external Engine Centers varies by Engine Center and by product or service. Pratt competes for part repair and part replacement contracts with other vendors, and does not receive 100% of the market share for every customer, product, and service. Therefore, market share

information is an important variable that affects the accuracy of external demand forecasts. In contrast, Pratt senior management dictates that PWAS will receive 100% of the part repair and part replacement operations outsourced by internal Pratt Engine Centers.

3. Pratt does not have direct access to historical transactional data for overhauls completed in external Engine Centers. The history of actual demand patterns in these external shops is more difficult to access and to analyze directly. In contrast, Pratt has complete access to all historical operational data for overhauls performed internally via the ERP database.
4. External Engine Centers can have different operational standards, and therefore generate different part demand patterns. In contrast, Pratt Engine Centers have relatively standardized operations across internal Pratt Engine Centers, which generates similar part demand patterns.

### 3 Chapter 3. The Sales Forecasting Process

Thomas Wallace, in his book “Sales and Operations Planning”, describes the role of Sales and Marketing in the forecasting process:

*Sales and Marketing people “own” the Sales Forecast. It’s their job; and they’re the experts on the demand side of the business, both in planning and execution...They own it, because they sell it. They’re the company’s primary contact with the customers, who are - after all - the drivers of demand.*<sup>13</sup>

Wallace’s statement about the role of Sales and Marketing in the forecasting process is consistent with the philosophy of Pratt & Whitney. Sales and Marketing is responsible for publishing the official Pratt & Whitney Sales Forecast. The Sales forecast covers both original equipment manufacturing (OEM) and Aftermarket Services, for both the Commercial Aviation Organization and the Military Aviation Organization. The official Sales forecast is published in several different forms, depending on the requirements and the mission of the intended end-user. As a result, Sales forecasts that are tailored for different organizations have different forecasting periods, content, and formats. This thesis will focus on the Sales forecast generated for the Commercial Aftermarket Services organization at Pratt, which is a generally a twelve-to-eighteen month forecast.

#### 3.1 Description of the Current Aftermarket Sales Forecasting Process

Aftermarket repair facilities currently receive an annual forecast from the Sales & Marketing organization. From an Aftermarket perspective, a “sale” refers both to the sale of replacement parts and to the sale of services, such as engine overhauls and part repair services provided by Aftermarket facilities worldwide.

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<sup>13</sup> Thomas F. Wallace. *Sales and Operations Planning: The How-To Handbook*. (Cincinnati: T.F. Wallace & Co., 1999), 28.

The annual Sales forecasting process for Pratt & Whitney Aftermarket Services (PWAS) begins with input from the Aftermarket Sales representatives prior to the start of the Pratt fiscal year. The Aftermarket Sales representatives are located around the world, and are organized either by product and region (such as “Airfoils - Asia”), or by business unit (e.g. all repairs by a specific Engine Center or Part repair facility). The Sales representatives submit an annual forecast for the products or customers for which they are responsible. These forecasts are in the form of sales revenue forecasts, which are in dollar amounts, by product or by business unit.

These individual Sales forecasts are consolidated at Pratt & Whitney headquarters, matched against Sales targets set by senior management, and adjusted as necessary to match the Sales targets. The adjusted forecast is sent back to the individual Sales representatives, who review the adjusted numbers and provide feedback, which may produce further adjustments to the forecast. The adjusted forecast is also given to managers of the Aftermarket repair facilities and the Spares organization, who provide feedback such as the identification of capacity constraints, which may also produce further adjustments to the annual Sales forecast. This iterative process of updating the Sales forecast continues until the official Sales forecast is published, with interim updates published quarterly throughout the fiscal year.

### **3.2 Analysis of the Current Aftermarket Sales Forecasting Process**

Based on the scope and focus of this thesis, there are five important points to highlight about the current Sales forecasting process:

1. The format and content of the individual Sales forecasts provided by the Sales representatives is not standardized across all business units, products, and regions. Therefore, different Sales representatives can use non-standardized product and service names, as well as non-standardized customer names, to submit their forecasts to the Pratt & Whitney Sales headquarters.
2. Second, the process by which individual Sales representatives generate their individual forecasts is not standardized. There is no standard database or standard

Sales calculation method that is used by Sales representatives. Sales representatives can use locally-developed databases and forecasting processes to predict annual demand, or they can get this information directly from their customers. Therefore, the quality of an individual forecast depends upon the quality of a Sales representative's operational knowledge, experience, and familiarity with customers and products.

3. Third, due to the nonstandard databases, processes, and formats utilized by individual Sales representatives, detailed analysis of the demand trends across PWAS is difficult to achieve. Information such as available market share by product and by customer is difficult to determine quickly and accurately from the non-standardized information. This difficulty in determining available market share can result in a forecast that is either too aggressive or not aggressive enough, depending on the specific market. Since Sales representatives are compensated based upon their ability to meet or exceed their individual sales forecast, a sales forecast that exceeds the available market share for a given market will result in the loss of financial compensation for the Sales representative. Similarly, a forecast that is not ambitious enough to gain a significant portion of available market share results in lost sales opportunities for Pratt & Whitney.
4. Due to the fact that the Sales forecast is basically a financial forecast, which is a dollar amount, the actual mix of physical products and services is difficult to translate accurately. The mix of individual products and services that Aftermarket repair facilities will experience is derived from this dollar value by using the average price for a particular product or service for a specific customer, calculated from the cumulative sales amounts from the previous year.

The first flaw in this conversion method is that it is founded on a sales revenue forecast that is generated from a manual, iterative, and non-standardized process. The current Sales forecast is not grounded on verifiable, standardized data, and

therefore the results of this forecast are prone to double-counting errors and other errors typical of non-standardized forecasting methods. As a result, the operational forecast that is derived from this sales revenue forecast is equally flawed.

Second, the current Sales forecasting process uses the historical average price to convert a sales revenue forecast (in terms of dollars) into an operational forecast (in terms of products and services), which neglects the differences in workscope mix from year to year. The cost of a repair or service depends upon the workscope of that particular repair, and the average price over a year depends upon the workscope mix of a repair or service within that year. If the products received in a future year display a significantly different workscope mix, then the historical average price will be inaccurate, and the current product demand derived from the sales revenue forecast will be also inaccurate.

5. The manual, iterative, and non-standardized nature of the current Sales forecasting process is extremely cumbersome and time consuming. The process for publishing forecasts, analyzing the accuracy of the forecasts, and publishing future updates requires significant time and effort by Sales representatives, Aftermarket operational managers, and the Sales & Marketing headquarters section. One objective of the new Aftermarket Demand Planning Process (ADPP) is to automate key activities in the current Sales forecasting process, thus requiring less time and redundant effort.

### **3.3 The Quality of the Sales Forecast from a Sales Revenue Perspective**

It is important to note that the annual Sales forecast is accurate in predicting annual sales revenues in terms of sales dollars. As part of a publicly traded corporation, the accuracy of the Pratt & Whitney annual sales revenue forecasts is critical for investors and senior management. The official Pratt & Whitney Sales forecast is viewed as credible and accurate in predicting cumulative sales revenues. However, as a financial forecast, the



sales forecast is difficult to translate into accurate operational forecasts for Pratt Aftermarket repair facilities.

There are three reasons that can possibly explain why existing Sales forecast produces sufficiently accurate annual sales revenue forecasts and insufficiently accurate operational forecasts.

1. The sales revenue forecast is updated regularly during the fiscal year, so the net result of the updates produces a sufficiently accurate annual Sales forecast. While the process for updating these sales forecasts is time-consuming and cumbersome, the sales revenue forecast can be updated and justified relatively quickly compared to operational forecasts. Aftermarket operational units cannot react quickly to large, unexpected shifts in demand, especially to large increases in demand or large variations in the product and workscope mix of demand.
2. From a cultural perspective, the financial forecast at Pratt & Whitney is paramount. Meeting and exceeding sales revenue targets, as well as meeting other financial goals such as earning before interest and taxes (EBIT), is the primary focus of most Pratt & Whitney managers. The Aftermarket operational details, such as part repair and part replacement mix, are typically secondary considerations. As long as the cumulative sales revenue targets and EBIT are achieved, inaccuracies in the operational forecast can be forgiven. Therefore, the Pratt & Whitney culture suggests that an Aftermarket sales revenue target should be achieved above all else, even if the operational forecasts are unreliable.
3. In many companies, the importance of meeting the sales revenue targets, as well as the compensation of Sales representatives based upon their ability to meet these targets, can hypothetically invite Sales representatives to develop gaming strategies to ensure they meet their sales targets. For example, a Sales representative may be more likely to submit a less aggressive sales forecast that is easier to achieve, than to submit a stretch forecast that increases the risk of losing his or her financial compensation.

Also, during the fiscal year, the aggressiveness and effectiveness of a Sales representative may depend on how well a representative is performing compared to the Sales target. For example, a Sales representative could become less aggressive once he or she is certain that he or she will meet the annual sales targets. Similarly, a Sales representative that is below his or her Sales targets could become more aggressive, and perhaps seek new sales opportunities for products and services that are not included in the original operational forecast.

It is important to emphasize that the gaming strategies described above are hypothetical. Gaming strategies were not explicitly observed in the research that supports this thesis, nor were they the focus of the research. However, the important point is that the current Sales forecasting process creates an environment where *the possibility exists* for Sales representatives to employ gaming strategies as described above. The net result of these hypothetical gaming strategies, if employed by Sales representatives, is the artificial control of Aftermarket demand in order to meet sales targets, which could introduce further inaccuracies into the operational forecasts.

A major benefit of the ADPP, which is the focus of this thesis, is that it restricts the ability of Sales representatives to employ gaming strategies by providing a data-based method for accurately determining available market share. The identification of available market share limits the ability of Sales representatives to submit non-aggressive or overly aggressive forecasts. Also, through the use of the ADPP, the quality of the operational forecast is equally important as the quality of the sales revenue forecast, and unexpected deviations from the operational forecast can be identified and analyzed quickly.

### **3.4 The Quality of the Sales Forecast From an Aftermarket Operational Perspective**

From an operational perspective, the official Sales forecast does not provide the level of operational detail necessary for Aftermarket managers to optimize their operations. Aftermarket repair facilities require information such as a detailed product mix and volume by month, by customer, and by workscope. For reasons described in the previous section, managers at Aftermarket repair facilities do not receive the accurate operational forecasts they require to effectively run their operations. Therefore, the current Sales forecast does not sufficiently alleviate demand uncertainty from the perspective of the Aftermarket operational managers.

To alleviate the problem of demand uncertainty, a manager at an Aftermarket repair facility has several options. The two most common options exercised by Aftermarket operational managers to combat demand uncertainty are direct contact with the customers and increased inventory. Similar to Sales representatives, managers at Aftermarket repair facilities can get the operational information they require directly from their habitual customers, which is redundant effort with the Sales representatives. Also, the operational managers can increase inventory to account for uncertainties in demand, which equates to an increase in costs incurred by operational units and an increase in costs passed along to the customer.

### **3.5 Information Technology: Improving the Forecasting Process**

The Sales and Marketing organization is aware of the problems and shortcomings inherent in generating accurate operational forecasts using the existing Sales forecasting process, and is actively seeking ways to overcome these problems. The evolution of sophisticated data storage and data analysis systems over recent years provides a basis for developing a data-based forecasting process that can generate accurate operational forecasts from the existing Sales forecasting process. PWAS and the demand planning team, with access to historical operational demand data, are in a unique position to help Sales and Marketing develop a better forecasting process.

An initiative that promises to standardize data and processes across PWAS is the implementation of Enterprise Resource Planning (ERP) systems across Aftermarket repair facilities. The method for mining this standardized, historical operational data from ERP systems and using it to generate reliable and accurate operational demand forecasts is the basis for the Aftermarket Demand Planning Process (ADPP) and the focus of this thesis.

## **4 Chapter 4. The Conceptual Basis For the Aftermarket Demand Planning Process**

The Aftermarket Demand Planning Process (ADPP) is a new initiative within Pratt & Whitney that promises to change the way in which Pratt views global Aftermarket demand, as well as the way Pratt predicts that demand. Since the ADPP is a new initiative that has not been previously attempted at Pratt & Whitney Aftermarket Services, it is crucial that the demand planning team spend considerable time and effort educating leaders and potential end-users about the conceptual basis and the necessity of a forecasting process such as the ADPP. This chapter introduces the conceptual framework, goals, and objectives of the ADPP.

### **4.1 Introduction to the Aftermarket Demand Planning Process**

Recognizing the limitations and challenges inherent in the existing demand forecasting process, the Aftermarket demand planning team conceptualized an improved forecasting process capable of providing both the Pratt & Whitney Sales organization and the Aftermarket repair facilities with a data-driven, verifiable, and standardized part-type demand forecast. This improved process, called the Aftermarket Demand Planning Process, is not intended to replace the existing Sales forecasting process, but rather intended to supplement portions of the existing Sales forecasting process by automating key steps. As an additional benefit, ADPP will generate and utilize a single, standardized set of operational data from which all organizations within Pratt & Whitney can use as a basis for cross-functional decision-making. The demand planning team will continually seek to standardize data at all levels in the ADPP development process and within the supporting databases.

The intended end-users of this process for Phase 1 and Phase 2 are the Aftermarket repair facilities, the Sales organization, and Spares. However, many other organizations within Pratt & Whitney can benefit from standardized operational data and from a data-driven global demand forecast. Additional end-users for future phases of the ADPP are discussed Chapter 8.

The ADPP will provide Aftermarket repair facilities and Spares with reliable operational forecasts, as well as serve as an important tool to aid the Sales organization in their market analysis and in the formulation of their annual global demand forecast.

#### **4.2 The Operational Perspective: The Foundation of the Aftermarket Demand Planning Process.**

Thomas Wallace, in his book *Sales and Operations Planning: A How-To Handbook*, states that the primary job of a forecaster in a manufacturing firm is to produce a forecast that is "...good enough to enable Operations people to do a proper job of initial procurement and production, [and] capacity planning."<sup>14</sup>

In this spirit, the Aftermarket demand planning team began developing the new forecasting process by first analyzing the Aftermarket business from a purely operational perspective. An operational perspective, as defined by the demand planning team, involves examining Aftermarket demand from the perspective of a Materials Manager or a General Manager in a Pratt & Whitney Aftermarket repair facility. In order to manage their operations most effectively, a General Manager or a Materials Manager at an Aftermarket repair facility requires sufficiently detailed operational data. This information includes, but is not limited to, accurate information on how many engines to expect by month over the next year or more, listed by engine model and workscope, as well as the expected part demand that those engines will generate, both in terms of repair parts and scrap replacement parts. Armed with this information, the General Manager can compare expected demand with capacity, identify imbalances, and work to correct those imbalances proactively. Using this same information, a Materials Manager, along the Pratt & Whitney Spares organization, can more effectively manage the inventory of scrap replacement parts, thus reducing inventory holding costs and part replacement lead times.

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<sup>14</sup> Thomas F. Wallace. *Sales and Operations Planning: The How-To Handbook*. (Cincinnati: T.F. Wallace & Co., 1999), 28.

Providing accurate operational information critical to an Aftermarket repair facility manager is the focus of the ADPP development. The demand planning team, with an operational perspective of Aftermarket demand, will continue to refine the capabilities and the outputs of the ADPP to meet the needs of the operational managers.

Currently, the operational details important to Aftermarket repair facilities, such as part repair and scrap replacement volumes, are derived from a financial forecast through a conversion process, as discussed in Chapter 3. The result is an operational forecast that lacks the necessary details and accuracy required by Aftermarket repair facility managers. The dominance of the sales revenue perspective in the current Sales forecasting process produces accurate sales revenue forecasts, but fails to provide the repair facilities with a sufficiently reliable engine and part demand forecast.

Understanding the difference in perspectives between the Aftermarket Demand Planning Process and the existing Sales forecasting process is crucial to understanding the underlying “physics” of each process, which in turn is crucial to identifying the potential capabilities and limitations of each process.

### 4.3 How PWAS Creates Value

*The purpose of a firm is to create value. Profitability is merely an occasional outcome.*<sup>15</sup>

- Michael Hammer

*Value is what buyers are willing to pay, and superior value stems from offering lower prices than competitors for equivalent benefits or providing unique benefits that more than offset a higher price.*<sup>16</sup>

- Michael Porter

In order to develop a forecasting process that would be accepted and implemented across the entire Pratt & Whitney Aftermarket organization, the demand planning team sought to develop a process that enhanced the ability of Pratt & Whitney Aftermarket Services (PWAS) to create value for its customers. The demand planning team believes that a forecasting process consistent with the fundamental value proposition of PWAS will satisfy the cross-functional requirements of organizations associated with the Aftermarket business. Furthermore, a forecasting system that meets cross-functional requirements of multiple organizations with Pratt stands a much greater chance of gaining acceptance into the Pratt & Whitney business process.

With a focus on value from a customer's perspective, the demand planning team contends that PWAS creates value for its customers based on the following:

1. High Quality Service
2. Reliable Delivery Performance (engine "Turn Time")
3. Low Cost

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<sup>15</sup> Michael Hammer, quoted April 2, 2003, in a lecture at MIT for Course 15.379, "Operations Strategy".

<sup>16</sup> Michael E. Porter, *Competitive Advantage* (New York: The Free Press, 1985), 3.



Customer satisfaction is achieved by Aftermarket repair facilities through high-quality engine overhaul or part repair services, within the time limits and cost provisions promised by the Sales contract. Given this framework, a repair facility can increase customer satisfaction through faster engine turn times, shorter part replacement lead times, decreasing inventory holding costs and costs due to re-work (savings that can be passed along to customers), and consistently high quality. The Aftermarket Sales representatives can increase value by identifying markets of opportunity, which translate into identifying customer needs, and by creating demand for PWAS services. The continued growth of PWAS, and its ability to capitalize on the tremendous growth potential of the worldwide Aftermarket business, depends upon its ability to create this value for customers.

Therefore, a forecast is valuable when it empowers PWAS to create value for its customers. Specifically, a valuable forecast is one that provides Aftermarket repair facilities with the information necessary to deliver high quality repair/replacement services, with faster repair turn times and lower costs that can be passed along to the customer. The demand planning team believes that the existing Sales forecast does not sufficiently provide this required level of information to repair facilities. As a result, the value that Aftermarket repair facilities provide to its customers is not optimized. The ADPP is a forecasting process that promises to deliver this level of detailed information, and once fully implemented, can optimize the ability of Aftermarket repair facilities to deliver value to customers.

The demand planning team does not intend to suggest that an accurate sales revenue forecast is not important. The current Sales forecasting process is extremely accurate in predicting annual sales revenue targets. The ability of a publicly-traded corporation to meet or exceed its sales revenue forecasts is crucial to shareholders and other key stakeholders.

However, while meeting financial targets is important to Pratt management and UTC shareholders, it does not necessarily create value for customers of PWAS. Therefore, a forecast that is focused solely on accurate financial targets is fundamentally misaligned with the customer's perspective of value. An accurate operational forecast and an accurate financial forecast are equally important, and with the implementation of the ADPP, equally attainable.

#### **4.4 The Goals**

The ultimate goal of the Aftermarket demand planning team is to develop a data-driven process for producing a web-based, monthly, reliable, and accurate part demand volume forecasts for all Aftermarket repair facilities worldwide. Also, the demand planning team will provide the Sales and Marketing organization with an improved, automated process for generating annual Aftermarket sales revenue forecasts.

The ADPP will utilize a worldwide monthly **engine shop visit forecast**, delineated by engine model, workscope, customer, and engine overhaul center, and produce the following output:

- A monthly part-type repair demand forecast for all Pratt & Whitney Engine Overhaul Centers and Part Repair Facilities. The method used to define part-type aggregation is described in Section 5.4.
- A scrap replacement forecast to the Pratt & Whitney Spares organization, by Engine Center and part-type.
- A monthly part-type demand forecast for use in the Sales forecasting process.
- A standardized Aftermarket demand data set for use by all organizations across Pratt & Whitney.

#### **4.5 The Three Development Phases**

Development and implementation of the ADPP is divided into three phases. Although the scope of this thesis is limited to Phase 1 of the development and implementation schedule, a brief overview of the scope and the objectives of all three phases are listed below:

**Phase 1:** Develop a process and supporting tools to mine and analyze Enterprise Resource Planning (ERP) data from Pratt & Whitney Engine Centers to produce an *internal* part-type demand forecast. The forecast will be presented by month for three months out, then quarterly for the next year, for a total of 15 months in the forecasting period. Internal demand in Phase 1 is the demand generated by repair operations performed on engines in the five Pratt & Whitney Commercial Engine Centers. Refer to Section 2.7 for a discussion on the differences between internal and external demand.

**Phase 2:** Expand the process to analyze *external* demand and produce a global part-type demand forecast for all Aftermarket repair facilities worldwide. Also, expand the scope to provide the Sales organization with the information necessary to generate an annual sales forecast. External demand in Phase 2 is defined as demand generated by repair operations of the following:

- All Pratt & Whitney Engines overhauled by internal and external engine overhaul shops.
- All Engines (both Pratt & Whitney engines and competitor engines) repaired in Pratt & Whitney Engine Centers.

**Phase 3:** Refine the ADPP based on feedback from end-users. Also, incorporate all supporting information sources, such as input from “Fly Forward” and input from the **Sales and Operations Planning (S&OP)** initiative. “Fly Forward” is discussed in Section 4.5.1 and S&OP is discussed in Section 8.3.

#### **4.5.1 The Necessity of a Three-Phased Implementation Schedule.**

*Design big, but implement in stages.*<sup>17</sup>

- Michael Hammer

The three-phased implementation schedule is necessary for several reasons. First, the task of analyzing global Aftermarket demand and identifying patterns is challenging and time consuming given the immense amount of data. The three phases of implementation

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<sup>17</sup> Michael Hammer, quoted April 2, 2003, in a lecture at MIT for Course 15.379, “Operations Strategy”.

allows the demand planning team to start with a subset of global demand information that is the least complicated, such as internal demand in Phase 1, and develop personal skills, computer logic, and business processes that are necessary to properly analyze information and to generate a forecast. With the ability to analyze internal demand and generate an internal demand forecast, the demand planning team can apply this knowledge to increasingly complex environments, such as the external demand environment.

Second, the ADPP relies on several key information sources and business processes that are being developed concurrently with the ADPP. The pace of implementation for the ADPP is dependant upon the pace at which these supporting data sources and business processes are implemented. For example, the Enterprise Resource Planning system is currently being implemented in phases across the Pratt & Whitney Aftermarket repair facilities. A complete internal and external demand forecast requires ERP data from all Engine Centers and part repair facilities, which is still some months away.

However, the demand planning team can focus on Engine Centers and part repair facilities that are currently using ERP, develop computer tools and data-mining logic to extract ERP data, analyze trends, and generate a forecast. With the data-mining logic and analysis tools in place, along with an established business process for generating a forecast, the ADPP can quickly expand its scope to include data from other facilities as they implement ERP.

Also, the “Fly Forward” initiative, which provides an essential input into the ADPP, is another data source that is being developed concurrently with the ADPP. The goal of the “Fly Forward” initiative is to generate a **worldwide engine shop visit forecast** delineated by month, by engine model, by workscope, and by Engine Center. *It is this engine shop visit forecast that the ADPP will convert into a global part-type repair forecast.* Implementation of the “Fly Forward” initiative will not occur until late in Phase 2 or early in Phase 3 of the ADPP. In the meantime, the demand planning team can

develop a structure that converts “Fly Forward” input into a global part-type demand forecast, and implement that structure once “Fly Forward” is completed.

#### **4.5.2 Phase 1 Data Source: The Cheshire Engine Overhaul Center**

For Phase 1, the Aftermarket demand planning team will focus on the ERP data collected at the **Cheshire Engine Overhaul Center** in Cheshire, Connecticut. We chose to focus on the ERP system at Cheshire because the Cheshire facility was one of the first Engine Centers to implement ERP and it is located within a short driving distance from our headquarters in East Hartford, Connecticut. The longer a facility uses ERP, the larger the data sample size, which makes historically-based forecasting methods more accurate. Also, facilities that have more experience with ERP commit fewer data-entry errors than facilities that are less experienced with the system. The result is cleaner ERP data from the more experienced facilities.

An underlying assumption of the demand planning team in using ERP data from one Engine Center is that operations among the Pratt & Whitney Engine Centers are very similar. The trends we identify in the ERP data from the Cheshire facility will be applied to predict demand for all five Engine Centers in Phase 1. This assumption will be tested as the data-mining logic is expanded to retrieve data from all five Engine Centers early in Phase 2. If different historical trends are discovered among the five Pratt Engine Centers, then the demand planning team can develop separate historical trend models for each facility and analyze potential causes for these differences.

The ERP data described in this thesis for Phase 1 is from the Cheshire Facility, unless otherwise noted.

#### **4.5.3 Phase 1 and Phase 2 Outputs**

Phase 1 and Phase 2 implementation of the Aftermarket Demand Planning Process differs mainly in scope. In Phase 1, the focus is on capturing, analyzing, and forecasting *internal* demand. In Phase 2, the project evolves to include an analysis and forecast for *external* demand. Despite this difference in scope, the outputs are very similar.

The output of these two phases is a web-based system with the following capabilities:

1. Allows each Pratt & Whitney repair facility, including Engine Centers and part repair facilities, to log on to a secure website and view their specific repair parts volume (based on their repair capability), by part-type, by customer, by month and quarter.
2. Allows the Pratt & Whitney Spares organization to log on to view the scrap replacement requirements from Pratt & Whitney Engine Centers, by location, by part-type, by month and quarter.
3. Allows Sales and Marketing to log on to a secure website and view global part-type demand forecasts delineated by region, by customer, by part-type, and by engine overhaul facility.
4. Allows the administrator (the demand planning team) to view the overall demand, repair and scrap replacement by business units, engine centers, and engine modules. This function will allow the demand planning team to refine the ADPP based on increasing amounts of historical data.

#### **4.6 Enterprise Resource Planning: The Standard Database**

Using an operational perspective, the Aftermarket demand planning team began conceptualizing the ADPP by identifying what we believe is a fundamental problem with the existing Sales forecasting system: the lack of a standard, verifiable data set from which to base an analysis of Aftermarket global demand. As a result, the demand planning team sought to identify a standard source of data within Pratt & Whitney Aftermarket Services.

A database that promises to standardize internal operational data across all Aftermarket repair facilities is the Enterprise Resource Planning (ERP) system that is being implemented in phases. Since the implementation of ERP across the Pratt & Whitney repair facilities was a relatively recent initiative at the time we began work on the ADPP, the members of the demand planning team had limited knowledge about the data content and architecture of the ERP database. We therefore invested considerable time and effort in the early stages of the development process to study the data content and structure of

the ERP database. We quickly determined that the ERP database would suffice as a raw data source for our demand planning process.

As discussed in Section 4.5.2, the demand planning team focused on extracting and analyzing ERP data from the Cheshire Engine Center for Phase 1. With this standard operational data source identified, the Aftermarket demand planning team turned its attention toward developing computer logic to mine this data and toward creating a process for converting this data into a global part-type demand forecast.

#### **4.6.1 The Conceptual Approach: Identifying Historical Trends in ERP Data**

Our approach centered on creating a framework to mine, cleanse, aggregate, and analyze ERP data so that we could easily identify historical patterns within the immense amount of operational data. Using these observed patterns in the ERP operational data, the demand planning team could gain an insight into the actual nature of Aftermarket demand experienced by the Aftermarket repair facilities and define the basic information required by repair facilities to operate effectively. With this basic understanding of Aftermarket demand, the Aftermarket demand planning team could ultimately generate a demand forecast with the necessary level of detail required by Aftermarket repair facilities.

The concept of analyzing the actual demand history (*actual demand consumption*) rather than analyzing the historical *orders* for repair and replacement parts represents a key differentiator between the ADPP and other demand planning initiatives at Pratt. The ADPP is the only demand planning initiative at Pratt that is based on identifying true historical demand rather than based on identifying historical orders for repair or scrap replacement parts. Orders can be modified, and therefore an analysis of historical orders does not capture the true demand signal experienced by Aftermarket facilities. As a result, only the ADPP can identify true historical demand patterns and use those true demand patterns to accurately predict future demand patterns. This key capability of the ADPP to capture true demand is a significant reason for its growing acceptance by all organizations within Pratt & Whitney.

The immense amount of information stored in the ERP database does not readily lend itself to simple trend analysis. The demand planning team realized quickly that an unstructured analysis of the entire ERP database would be time-consuming and would perhaps yield mixed results. The demand planning team decided instead to first determine the information required to support the ADPP, and then develop tools for mining this information from ERP.

#### **4.6.2 Using ERP Data to Generate a Model of the Engine Overhaul Process**

In order to determine the information required for the ADPP, the demand planning team started by analyzing the physical flow of an engine through a Pratt & Whitney Engine Center. Based upon the operational experience of the demand planning team, we quickly identified patterns in the physical flow of an engine through an Engine Center.

Although an Engine Center typically repairs several different engine models with varying worksopes, the vast majority of engines that flow through a Pratt & Whitney Engine Center follow a standard pattern from induction through final shipping to the customer.

The identification of this physical pattern is important for three reasons. First, identifying the physical pattern serves as a guide for our ERP data collection and analysis efforts. Using the observed physical pattern of an engine flow through an Engine Center, we could develop tools to mine the specific ERP data that defined this common physical pattern.

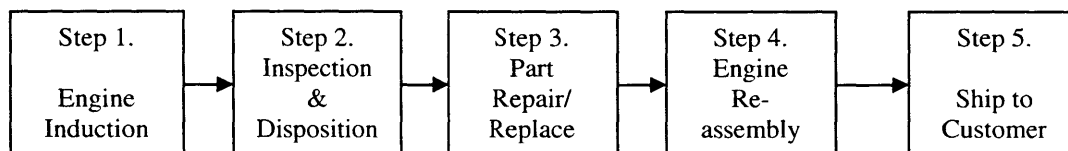
Second, recognizing similar patterns in the physical flow of an engine through an Engine Center provides the demand planning team with the fundamental conceptual basis for converting an engine induction schedule into a part-type demand forecast. If almost all engines follow a similar pattern throughout the overhaul process, then the demand planning team could conceivably analyze patterns among historical overhauls recorded in ERP and apply those historical trends to predict future demand patterns.



And third, this common pattern serves as a first step in our efforts toward reducing the perceived variability of global Aftermarket demand. The realization that almost every engine follows a similar pattern once inducted into an Engine Center is a critical first step toward understanding global Aftermarket demand and reducing the perceived variability of this demand.

#### **4.6.3 The Model of the Physical Flow of an Engine Through an Engine Center.**

Based on our analysis of the physical flow of an engine through the Cheshire Engine Center, the demand planning team was able to construct a physical engine flow diagram. Figure 4.1 below depicts the basic steps in the physical flow of an engine through a Pratt & Whitney Engine Center.



**Figure 4.1. The Physical Flow of an Engine Through a P&W Engine Center**

The steps in the flow of an engine through an engine center are as follows:

**Step 1. Engine Induction:** The engine is received into the Engine Overhaul Center from the customer.

**Step 2. Engine Disassembly and Technical Inspection:** The engine is disassembled and parts are inspected and assigned disposition codes ranging from “serviceable” to “repair” to “scrap” (requiring replacement parts). Part disposition codes are discussed in Section 2.4.2.

**Step 3. Part Repair or Scrap Replacement process:** Based upon the part disposition codes, parts are disseminated to a variety of possible repair facilities. For part repair operations, parts can be shipped to Engine Center repair cells, Pratt & Whitney part repair facilities, or external vendors. Parts coded as “Scrap” require replacement parts from the Pratt & Whitney Spares organization. The lead times and costs incurred in this step can

vary significantly, depending on the repair facility, the level of repair, and the type of part.

**Step 4. Engine Re-assembly and Final Inspection:** The Engine Center gathers repaired or replaced parts and re-assembles the engine. Engine is also tested once re-assembled.

**Step 5. Final Shipping:** Engine is shipped to customer.

#### **4.6.4 Identifying ERP Data That Defines the Physical Engine Flow**

Once we identified the physical pattern of an engine flow through an Engine Center, we could then identify the transactional data stored within the ERP database that defined each step. The result is a framework that allows the demand planning team to sift through large amounts of ERP transactional data and mine only the pertinent data that defines the five steps listed in Section 4.6.3. From a demand planning perspective, the following is a list of the pertinent information that is recorded in ERP for each step in Figure 4.1:

##### **Step 1. Engine Induction.**

- a. Engine Serial Number
- b. Engine Family, Engine Model, and Engine Thrust Code
- c. Date of Engine Induction to the Engine Center
- d. Customer
- e. Engine Flight History (number of cycles and hours flown).

##### **Step 2. Engine Disassembly and Technical Inspection at the Engine Center.**

- a. Engine Workscope Listed as Light, Medium, or Heavy Overhaul.
- b. Part Configuration (by Serial Number, also known as Part Number) of Engine.  
Part configuration is recorded only for parts inspected, therefore the level of part configuration detail that is recorded in ERP during an overhaul is dependant upon the workscope.
- c. Part Disposition Code. Each part is inspected at the Engine Center and assigned one of five possible ERP part disposition codes: “S”, “E”, “I”, “Rv”, or “Rb.” Refer to Section 2.4.2 for a definition of these codes.
- d. Module Workscope. Each individual engine module is assigned a workscope

which is more detailed and reliable than the overall engine-level workscope.

### **Step 3. Part Repair or Scrap Replacement Process.**

- a. External Repair Facility Information. For parts requiring external repair, the Part repair facility name and location are recorded in the Engine Center ERP database along with the corresponding part number. Using this data, we can construct historical Engine Center-to-External-Vendor relationship statistics described in Section 7.9.
- b. External Repair Facility Disposition Code. Parts that are shipped to an external facility for repair are inspected by the repair facility once they are received. An external repair facility can accept the repair disposition assigned by the Engine Center or it can code the part as Scrap (“Rv”) and order a replacement part.
- c. Total Component Labor Hours. A metric that can be used to confirm the workscope of an engine or a section within an engine. A high cost or a high number of labor hours associated with a specific engine section indicates a heavier workscope.

### **Step 4. Engine Re-assembly and Final Inspection.**

- a. Part Repair Turn Times. Repair turn times (in days) measure the total time elapsed from the time a repair facility receives a part, completes the required repair, and returns the part to the Engine Center for re-assembly. Repair turn times, also known as Operational Turn Times, serve as an important performance metric for repair facilities.
- b. Part Replacement Lead Times. The elapsed time for the fulfillment of a part replacement order is recorded in ERP.

### **Step 5. Final Shipping.**

- a. Engine Turn Time. The total elapsed time (in days) between Engine induction to Final Shipping. It is an important performance metric for Engine Centers and a critical customer service metric that correlates directly to the level of customer satisfaction. Engine overhauls are typically completed within 60-90 days.

The data listed above sufficiently defines the physical flow of an engine through a Pratt & Whitney Engine Overhaul Center. With the ability to retrieve this information, the Aftermarket demand planning team could essentially describe the physical flow of any engine overhaul recorded in the Pratt & Whitney ERP database. Moreover, if we could

define any individual engine overhaul based upon the pertinent data listed above, the Aftermarket planning team could also *aggregate batches of engines* based upon any number of criteria, including engine model, customer, or workscope, and search for historical demand patterns within these aggregated engine groups. This aggregation process, and its importance in the ADPP, is described in the next chapter.

## 5 Chapter 5. The Fundamental Data Aggregation Strategies for the ADPP

This chapter focuses on the hierarchy that the demand planning team uses to aggregate ERP data and examines how these aggregation criteria manifest themselves in the form of engine templates and the Typical Engine Part Disposition (TEPD) profiles.

The engine template and the TEPD convert an engine shop visit forecast into a part-type demand forecast, which is the cornerstone of the Aftermarket Demand Planning Process.

### 5.1 ERP Data Aggregation Levels: Engine Configuration vs. Part Configuration

Due to the immense amount of transactional data stored in the ERP database, the task of identifying patterns in the historical data requires the creation of a successful data-aggregation strategy. At a minimum, the demand planning team requires an aggregation strategy with two levels of aggregation detail: one level that defines engine groups based upon similarities in *engine configurations*, and another level that defines part groups based upon similarities in the *part configuration* and part repair processes within a group of engines.

An **engine configuration** is defined as the *overall structure of an engine* and the *overall structure of the modules* that make up an engine. For instance, engines with similar engine configurations will most likely have the same number of stages in the turbine and compressor, with similar or identical part quantities.

Engine configuration differs from the concept of **part configuration** in that part configuration refers to *specific part serial numbers* and *quantities of those specific part numbers* in an individual engine. Part number configurations represent a much more detailed and complex set of data than engine configurations. Part configurations can vary widely across engines, varying even across engines with identical engine configurations in the same engine family. In comparison, the number of engine configurations in the Pratt & Whitney Engine Fleet is relatively limited, whereas the number of possible part

configurations among engines in the operational fleet is extremely large and seemingly chaotic in nature.

### **5.1.1 An Illustrative Example of the Differences in Engine and Part Configuration: The PW2000 Engine**

The difference between an engine and part configuration is illustrated in the following example concerning the PW2000 engine family. A common characteristic among all engines within the PW2000 engine family is that they share the same number of stages in the turbine, the same number of stages in the compressor, the same number of fan blades, and so on. These similarities are the result of a similar *engine configuration* that all PW2000 engines share.

Furthermore, if we examine the turbine section of a PW2000 engine, we will find that each turbine stage has a specific *quantity of turbine blades* that differs from stage to stage. For example, all PW2000 engines have forty-eight turbine blades in the 1<sup>st</sup> stage turbine and sixty-four turbine blades in the 2<sup>nd</sup> stage turbine. The identical *engine configuration* of all PW2000 engines account for the identical number of turbine stages and the identical number of blades at each corresponding stage of the turbine.

In contrast, focusing again on the 2<sup>nd</sup> stage turbine, there are over twenty different part serial numbers in the Pratt & Whitney inventory that can function as a single 2<sup>nd</sup> stage turbine blade on the PW2000 engine. Any combination of these twenty different part numbers can constitute a full set of sixty-four 2<sup>nd</sup> stage turbine blades. Furthermore, these twenty different part numbers can have slightly different part names, because part names correspond only to part numbers and therefore names are not standardized across sets of interchangeable parts. These differences in part numbers, along with differences in part names, make the task of accurately tracking part number configurations of an engine extremely difficult.

If we expand the scope of the PW2000 example above to consider the entire engine, we know that the complete engine contains approximately 4500 parts. However, the *list of*

*possible part numbers* that constitute these 4500 parts can exceed 22,000 different part numbers, with almost every section in the engine having multiple interchangeable part numbers that can serve identical functions. At this level, the number of possible part number configurations for any complete PW2000 engine becomes extremely large and extremely difficult to predict accurately.

### **5.1.2 The Feasibility of Perfect Part Configuration Information in ERP**

One could argue that the ERP data should contain detailed part number configurations for all engines, specific to the engine serial number, thus eliminating the perceived uncertainty caused by the many possible part number combinations. However, the demand planning team has not found ERP part number configuration data to be sufficiently reliable for a number of reasons.

1. Only a small number of complete engine overhauls are recorded in the Aftermarket ERP database. Since ERP has only recently been implemented, the historical ERP database contains no part-number configuration information on the vast majority of engines in the Pratt & Whitney engine fleet.
2. The ERP system only records internal engine overhauls. Aftermarket ERP data only reflects information on engines that are overhauled at Pratt & Whitney Engine Centers, which represents the minority of the total number of engine overhauls performed on Pratt & Whitney Engines in an average year. At the present time, Pratt Aftermarket Services has no access to ERP information from external engine centers.
3. There is no guarantee that an engine overhauled at a Pratt Engine Center maintains its part number configuration between overhauls. A customer may perform minor repairs and part replacement operations at external engine centers, thus making the part number configuration data stored in Pratt's ERP system obsolete. Pratt currently has no process for capturing data from these external repairs.
4. The part number data in ERP is entered manually and therefore contains data-entry errors. There are thousands of parts that are inspected and dispositioned on a typical engine during an engine overhaul. The manual process of recording part numbers in ERP for thousands of individual parts is difficult to accomplish flawlessly, given that

even highly trained and highly skilled humans will make mistakes. The problem is further compounded by the fact that, on small parts such as turbine blades that are scorched by the intense heat under normal engine operating conditions, the tiny part serial numbers can be nearly impossible to read. The ERP system will accept any feasible part number that is in the system, so operators can conceivably record incorrect but feasible part numbers for a given section of the engine.

### **5.1.3 The Argument For a Part Number Configuration Strategy**

The good news is, with a clever part number aggregation strategy and a basic understanding of Aftermarket repair operations, specific information regarding part-number configurations of engines is not required to generate a useful part demand forecast. A successful part aggregation strategy eliminates the variability created by the large number of possible part number combinations on an engine. This part aggregation strategy requires a detailed analysis that will be presented in Section 5.5. However, before a successful part aggregation strategy can be implemented, the demand planning team first had to develop a successful engine configuration aggregation strategy. The engine configuration aggregation strategy employed by the demand planning team is discussed in the next section.

## **5.2 The Engine Configuration Aggregation Strategy**

A method for aggregating engines based upon engine configuration already exists within Pratt & Whitney. The engine configuration groups, as discussed in Section 2.4.1, are defined hierarchically as Engine Family, Engine Model, Engine Thrust Code, and Engine Serial Number. Recall that the broadest and highest level in this aggregation hierarchy is the engine family, while the most detailed and lowest level in the aggregation hierarchy is the engine serial number.

The demand planning team utilizes this existing engine aggregation hierarchy as the basis for grouping engines with similar engine configurations. Utilizing the existing engine aggregation hierarchy achieves synergy between the ADPP and many existing business process within Pratt. Many Pratt & Whitney business units and financial tracking metrics are aligned with this existing engine aggregation hierarchy. For instance, Aftermarket



repair facilities typically repair engines and parts from a specific set of engine models. Also, the “Fly Forward” initiative, which will provide a crucial input into the ADPP, will generate worldwide engine shop visit forecasts by engine model, which is consistent with the existing engine configuration hierarchy and the ADPP.

### **5.2.1 Determining Engine Configuration Groupings Within Engine Families**

The intent of the demand planning team is to group as many individual engine thrust codes and engine serial numbers as possible under the highest level in the existing engine aggregation hierarchy. Ideally, the demand planning team wanted to group engines purely by engine family, such as one engine configuration grouping for all PW4000 engines, one grouping for all PW2000 engines, one grouping for all V2500 engines, and so on. In order to achieve this, the demand planning team first had to determine whether or not all the engines in an engine family had identical or similar engine configurations.

The demand planning team discovered that, for certain engine families, not every model within an engine family shared the same engine configurations. Therefore, for engine families that include models with dissimilar engine configurations, multiple groupings are necessary to define the engine configurations of an entire family. As a result, the demand planning team developed 11 separate engine configuration groupings to define the 5 engine families that are the focus of Phase 1. A list of these 11 engine configuration groupings appears in Figure 5.1. It is important to note that the number of engine configuration groupings will expand in Phase 2, and the list in Figure 5.1 will continue to change as the ADPP evolves.

<u>Engine Family</u>	<u>Engine Model</u>	<u>Number of Configuration Templates</u>	<u>Template Name</u>
PW4000	94-inch	2	94-inch Phase 1 & Conversion 94-inch Phase 3
	100-inch	1	100-inch
	112-inch	3	112-inch, GB 112-inch, LB 112-inch, XB
PW2000	Commercial	1	PW2000, Commercial
V2500	A1	1	V2500, A1
	A5	1	V2500, A5
JT8D	200	1	JT8D-200
CFM56	N/A	1	CFM56

**Figure 5.1. List of Engine Configuration Groupings for Phase 1.**

These engine configuration groupings depicted above are captured in the ADPP by the creation of static engine templates. The concept of the static engine template is introduced in the next section, while Chapter 6 contains a complete discussion about the construction, content, and utility of the static engine template.

### **5.2.2 An Introduction to the Static Engine Template**

A static engine template represents the basic engine configuration strategy of the demand planning team, and is therefore an essential part of the ADPP. A static engine template resembles a bill of material, or a common list of parts, that is specific to a given engine configuration grouping.

Each engine configuration grouping identified by the demand planning team is represented by a separate static engine template. For Phase 1, the demand planning team constructed 11 static engine templates to correspond to the 11 engine configuration

groupings depicted in Figure 5.1. The important function of these templates within the ADPP is that, for all engines within an engine configuration grouping, the corresponding static engine template can convert these engines into parts. The ability to quickly and accurately convert an engine into its corresponding parts is a critical first step in defining the part-type demand that an engine generates, as will be discussed in Chapter 7.

The difference between a traditional bill of material and a static engine template is the unique part aggregation strategy employed by the static engine templates. This unique part aggregation strategy will be discussed in Section 5.5.

The key benefit in utilizing static engine templates is that, within each engine configuration grouping, this task of aggregating parts is simplified. Engines that share similar engine configurations have less variation in the number of possible part configurations and part repair processes. As a result, relatively simple part aggregation strategies can be developed and applied to all engines within the same engine configuration grouping.

From a data analysis perspective, the completed static engine templates, which represent both the engine and part aggregation strategies of the demand planning team, make it easier to identify trends within the historical ERP data. Instead of analyzing historical global demand using ERP data from many different engine configurations, with significant variations in engine structure, part quantities, and repair procedures, the demand planning team can use engine templates to search for patterns within engine configuration groupings with similar or identical engine structures and part quantities. Moreover, these engines with similar engine configurations will typically have similar part repair procedures, which is also useful in identifying historical repair demand patterns.

### **5.2.3 Multiple Static Engine Templates for a Single Engine Family: The PW4000 Example**

An example that illustrates the requirement for multiple static engine templates within a single engine family occurs in the PW4000 engine family. The PW4000 has three primary engine model groupings: the 94-inch, the 100-inch, and the 112-inch engine models, which refer to the diameter of the fan module for each model. The increasing fan diameter represents the evolution of the PW4000 engine design in order to achieve greater thrust output levels.

This evolution of the 94-inch engine model into the 100-inch and the 112-inch engine models was achieved through changes in the basic engine configuration of the 94-inch engine. The most notable differences in the engine configurations of the three engine models, besides the obvious differences in fan diameter, occur in the turbine and compression modules, which are the primary thrust-producing regions of the engine. Therefore, the demand planning team recognized that at a minimum, it would take three static engine templates to represent the three major engine models within the PW4000 engine family.

However, the sub-groupings for the PW4000 engine family did not stop with three static templates. Based upon the design improvements developed for the 100-inch and 112-inch engine models, the original offering of the 94-inch engine was upgraded in mid-production. The upgrade in the 94-inch engine design had two effects. First, engineers developed a retrofit package to convert previously built 94-inch engines into upgraded 94-inch engines. These engines are called “94-inch conversion engines.” And second, all 94-inch engines produced after the upgrade had a different engine configuration than the earlier versions of the engine. As a result, there are three different versions of the 94-inch engine, and two different engine configurations. The original 94-inch engine, called “Phase 1”, and the 94-inch Conversion engines share the same engine configuration, while the 94-inch Phase 3 has a separate engine configuration.

The result of our analysis of the differences in engine configurations within the PW4000 engine family led to the creation of six static engine templates to represent every possible engine configuration. The 112-inch engine also contains three separate versions with different engine configurations. The resulting list of engine templates for the PW4000 engine family appears in Figure 5.1.

### **5.3 An Introduction to the Two Dimensions of an Engine Template: The Static Portion and the TEPD**

An engine template is the cornerstone of the ADPP and the primary method used to convert an engine induction schedule into a part demand forecast. A template is a framework that allows the demand planning team to aggregate parts from engines with similar engine configurations. A completed engine template combines the engine configuration strategy with the part configuration strategy, and serves as a useful tool for ERP data extraction and trend analysis.

A completed template contains both a static and a dynamic portion. The **static portion of a template** resembles a bill of material or part-type configuration list for a given engine grouping, as discussed previously in Section 5.2.2.

The **dynamic portion of an engine template** depicts the entire repair or scrap history of every part-type on a particular engine, which are calculated using ERP data mined from Pratt & Whitney Engine Centers. This portion is “dynamic” because the part demand histories extracted from ERP can change, either as the data sample size increases over time or as different data-extraction and data-filtering criteria are employed.

The dynamic portion of an engine template represents a **Typical Engine Part Disposition** profile, or **TEPD**. A TEPD profile represents the complete part disposition history of a particular engine configuration grouping. A TEPD will depict repair and scrap ratios for each part-type on an engine, based upon any number of ERP data-filtering criteria. The data-filtering criteria that can be used to extract and analyze historical ERP part disposition data includes:

1. Customer-specific criteria. Using this criteria, a TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines owned by a specific customer.
2. Engine model specific criteria. Using this criteria, a TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines within a specific engine family, engine model, or engine thrust code.
3. Workscope-specific criteria. A TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines classified by a certain overhaul workscope, as in “all heavy overhauls.”
4. Region-specific criteria. Using this criteria, a TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines that operate in a desert environment as opposed to engines that operate in humid, tropical environments.
5. Engine Center specific criteria. A TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines overhauled at a particular Engine Center.
6. Time specific criteria. Using this criteria, a TEPD profile can be constructed to depict the entire ERP part repair and scrap history for all engines overhauled over a specified timeframe.
7. A combination of any and all the above criteria. Any combination of the above criteria can be used to generate many different demand histories, such as the demand history for all PW4000 engines owned by a specific customer that were overhauled at the Cheshire Engine Center. The demand planning team can apply the data-filtering criteria in any combination to analyze the actual ERP demand history generated by almost any conceivable demand scenario, which makes the TEPD profile an extremely powerful demand analysis tool.

The static engine template, with the ability to convert an engine into its parts, combined with a TEPD profile, which depicts the entire repair and scrap history of those parts, represents the cornerstone of the Aftermarket Demand Planning Process. The ADPP will

be discussed further in Chapter 7. The remainder of this chapter and the next chapter will focus specifically on the part aggregation strategies, and the process used by the demand planning team to construct static engine templates and TEPD profiles.

#### **5.4 The ATA Code: The Foundation for the Part Aggregation Strategy**

The success of the Aftermarket Demand Planning Process hinges upon the ability of the demand planning team to develop an appropriate part aggregation strategy within each engine configuration grouping. This part aggregation strategy focuses on defining patterns within the *part configuration* of an engine, which is apparently random in nature, for a given static engine template.

In order to identify an appropriate part number configuration strategy, the demand planning team once again relied upon operational knowledge of the Aftermarket business at Pratt & Whitney. The demand planning team realized that the standardization of information is essential for creating a forecasting system utilized across the entire organization. Therefore, the demand planning team sought to utilize existing standardized methods of aggregation whenever possible.

The part aggregation criteria that displayed the greatest potential for standardization across the Aftermarket business is the **Air Transport Association** code, or **ATA** code.

In the context of this thesis, the ATA code is a standard code that is used across the American aerospace industry to *catalogue the location of parts on aircraft engines*. Using the standard six-digit ATA code, the location of a part is catalogued by its linear position relative to the front, or fan intake section, of the engine.

Figure 5.2 depicts a partial ATA coding framework for the PW4000 engine. From Figure 5.2, one can quickly recognize the incremental ATA numbering logic as it increases from the front of the engine to the rear. Note that this ATA framework for this particular example depicts the ATA codes at the engine module level, as indicated by the “00” as the last two digits of the ATA codes (refer to the ATA codes in parenthesis in Figure 5.2). The first four digits of an ATA code for a part represents the engine module in

which the part is located, while the last two digits of the ATA code depicts the relative position of that part within the engine module.

For example, a compressor blade for a PW4000 may have an ATA code of “72-31-46.” The first four digits of the ATA code for the compressor blade, “72-31”, corresponds to the PW4000 engine module in which the part is located, which is the “Low Pressure Compressor” module as depicted in Figure 5.2. The last two digits of the ATA number will identify the location of the compressor blade within the Low Pressure Compressor module.

The parts on an engine are listed by part number and by the corresponding ATA code in the appropriate engine technical manuals and publications.



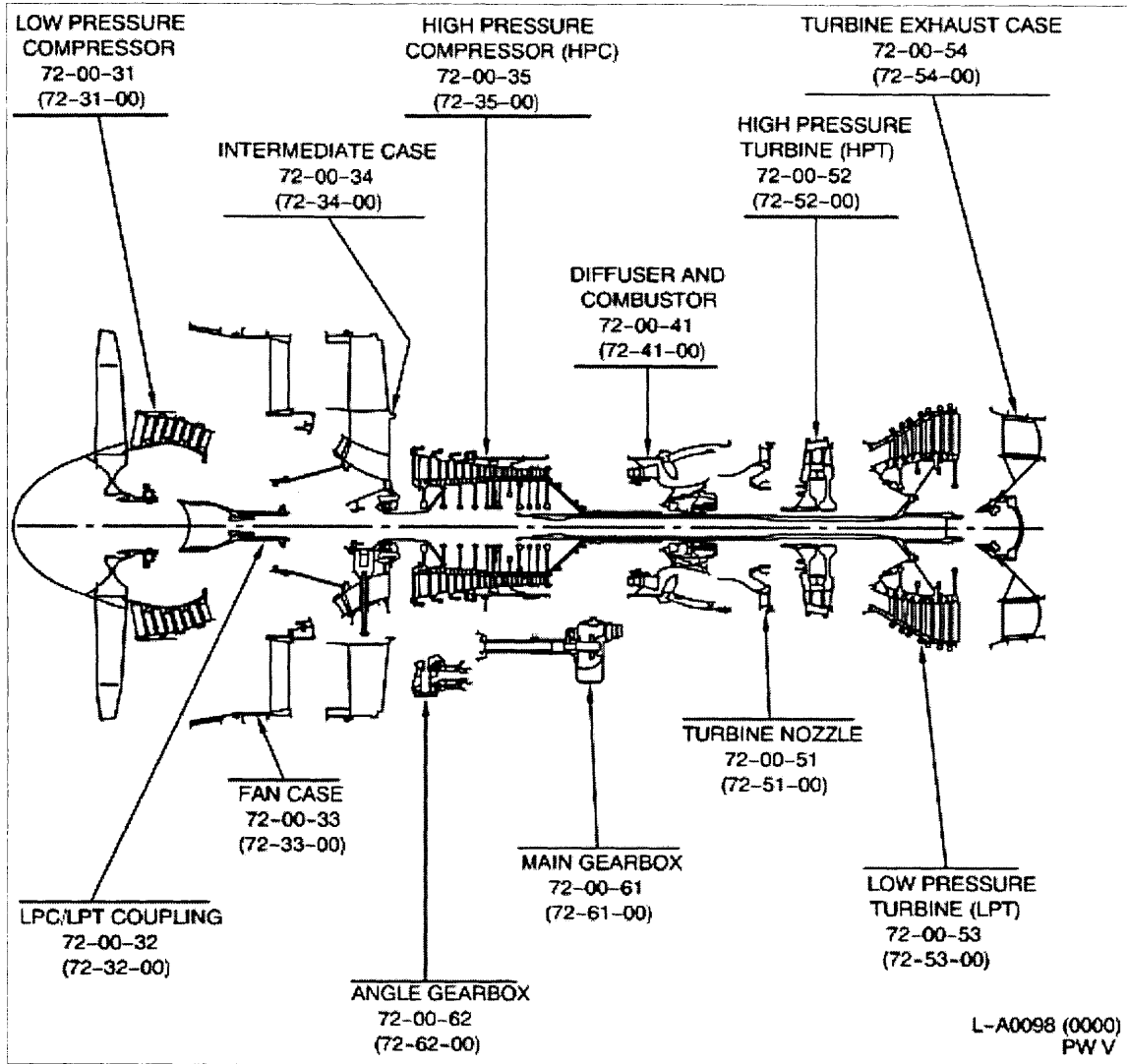


Figure 5.2. The Module-Level ATA Diagram of a PW4000 Engine.<sup>18</sup>

Note: Discussion in Section 5.4 refers to the ATA Code numbers listed in parentheses above.

<sup>18</sup> Pratt & Whitney. *Pratt & Whitney PW4000 Series Engine Manual (PN50A605)*. (East Hartford, CT: Pratt & Whitney, 1997); 6.

## 5.5 The Concept of the ATA Part Family: The Part Aggregation Strategy

As a major player in the American aerospace industry, Pratt & Whitney also utilizes ATA codes to catalogue the location of parts on its engines. Typically, this is accomplished by listing a part number with its corresponding ATA number together in an engine manual or technical publication. Pratt & Whitney engine manuals and technical publications define the ATA coding structure of a given engine model or engine model sub-group. Engine manuals and technical publications, along with part numbers and corresponding ATA coding frameworks, appear in the ERP systems at the Engine Centers for all Pratt Engines, thus making the data readily available for extraction using the data-mining algorithms developed by the demand planning team.

Therefore, since the ATA code is an industry standard system for cataloguing part locations that is recorded in the Pratt ERP systems, the demand planning team analyzed the feasibility of using the ATA code as the basis for the part aggregation strategy.

Before the demand planning team could adopt the ATA number as a basis for the part aggregation strategy, the team first had to determine if the ATA number could be used to generate forecasts with a sufficient level of operational information required by managers at Pratt Aftermarket repair facilities. Specifically, the demand planning team had to determine if parts within an ATA part family displayed similar repair or scrap histories, and if those parts were repaired using similar repair processes.

In its purest form, the ATA-based part aggregation strategy suggests that *all parts that share the same ATA code within a defined engine configuration grouping (i.e. static engine template) are grouped into an ATA part group, or ATA part family.* The example presented in Section 5.1.1 concerning PW2000 2<sup>nd</sup> Stage turbine blades will illustrate the concept of the ATA part family. Recall that a PW2000 engine has sixty-four turbine blades in the 2<sup>nd</sup> stage turbine, with twenty different part serial numbers in the Pratt inventory that can serve as a single 2<sup>nd</sup> stage turbine blade. The ATA number for all PW2000 2<sup>nd</sup> stage turbine blades is “72-52-17.” All sixty-four blades share this

ATA number, or address, on a PW2000 engine, regardless of the differences in individual part numbers that can constitute a full set of sixty-four blades.

Under the ATA-based part aggregation strategy, all sixty-four turbine blades on a PW2000 engine are grouped under the same ATA number, “72-52-17.” More importantly, the sixty-four turbine blades are assigned a **standard ATA part group name**, such as “Blade, 2<sup>nd</sup> Stage Turbine, PW2000”, and an **ATA group quantity**, which is “64” in this example. As a result of this aggregation strategy, all twenty individual part numbers are assigned the same ATA group name and quantity, which is an example of data standardization within the ADPP. Eliminating the individual names for part numbers within an ATA part family is essential to properly aggregate parts and to reduce a source of variability in the data.

### **5.5.1 Examining the ATA Part Family Concept from both a Sales and an Aftermarket Operational Perspective.**

The demand planning team analyzed the viability of the ATA part family framework from the perspective of the end users. In order to serve as a useful aggregation strategy, the ATA part family framework had to sufficiently reduce or eliminate part configuration variability while satisfying the information requirements of the end users. Stated more simply, the aggregation criteria must be broad enough to reduce or eliminate detail variability, yet detailed enough to provide useful information to end-users.

The major end-users for the ADPP, at least initially, are the Aftermarket repair facilities, Sales & Marketing, and Spares. This section will explore the information requirements for Aftermarket repair facilities and Sales. The requirements for Spares will be addressed in the next section.

The demand planning team determined that the ATA part family aggregation criteria satisfies the information requirements of both Sales and the Aftermarket repair facilities. The existing Sales forecasting process utilizes a comparable part aggregation strategy, or

product aggregation strategy, to track and report annual sales figures. The problems inherent in the current Sales forecasting process, described in Chapter 3 includes both the lack of sufficient and reliable operational details in the Sales forecast and the lack of standardized data. The ATA part family aggregation criteria is a more sophisticated part aggregation strategy that standardizes ATA part family names, quantities, and engine configurations, while providing Aftermarket repair facilities with a sufficient level of operational detail based upon reliable and verifiable data. The Sales organization can take the raw information generated by the ADPP, which is standardized and therefore easier to analyze, and use it as an input to generate sales revenue forecasts, to identify market opportunities, and to generate any other information requirements.

From the perspective of the Aftermarket repair facilities, the ATA code is utilized and recognized across Aftermarket Services. The ATA coding frameworks are stored along with operational data in Pratt ERP systems. Repair facilities often utilize a part number and its corresponding ATA number to record part transactions in ERP. The utilization of ATA codes across all Pratt & Whitney Aftermarket Services makes the ATA part family aggregation strategy appealing as a standard aggregation strategy.

More importantly, from a repair perspective, an aggregation strategy based upon ATA codes sufficiently describes the operational reality of a repair unit. Parts with similar structures and functions often share the same ATA code, and are often repaired using similar or identical process and repair lines. Therefore, a repair unit tends to view demand by part-type instead of by individual part numbers, which is consistent with the ATA part family aggregation strategy.

For example, referring back to the example in Section 5.1.1, the PW2000 has twenty different part numbers that function as 2<sup>nd</sup> Stage Turbine Blades. These different part numbers are the result of incremental engineering upgrades, such as additional air ventilation holes, or the result of small structural variations necessary to maintain a certain spacing or weight distribution within the rotating turbine. As a result, the twenty different part numbers that function as PW2000 2<sup>nd</sup> Stage turbine blades have relatively

small differences among them, and the differences in shape and weight among the part numbers are practically unnoticeable. More importantly, each PW2000 2<sup>nd</sup> Stage turbine blade is repaired using the same process, regardless of the individual part number. All twenty separate part numbers are repaired on the exact same repair line in the same part repair facility. Therefore, for Aftermarket repair operations, detailed part number information is unnecessary. The important quantity that operational General Managers and Materials Managers prefer to know is the total number of *part-types*, such as the total number of PW2000 2<sup>nd</sup> Stage Turbine blades, that will be inducted in a given month, rather than the quantity of individual part numbers that will be inducted. All PW2000 2<sup>nd</sup> stage turbine blades will be repaired using the same machines and repair lines, so the aggregate number of blades is sufficient information for a manager at a repair facility.

Therefore, the demand planning team concluded that the ATA code is a sufficient criteria for aggregating parts within an engine because it is consistent with the requirements of the operational repair units, and it eliminates the variability caused by the multiple part number combinations possible across engines.

However, as with any aggregation criteria, there are exceptions to the ATA part family aggregation strategy. The demand planning team developed a process to identify and address these exceptions, which is described in Section 5.5.3.

### **5.5.2 Examining the ATA Part Family Concept from a Spares Perspective**

Several organizations within Pratt & Whitney Aftermarket Services, such as Spares, require a more detailed method of cataloging parts than the ATA coding structure provides. These organizations prefer to utilize part serial numbers as the primary part tracking system due to the increased accuracy and level of detail offered by part serial numbers. Organizations such as Spares replace parts on a one to one basis, or a part-number-for-part-number basis, therefore they require an equally detailed method for forecasting and tracking parts. However, due to the chaotic nature of part number configurations among engines and the lack of reliable part configuration data in ERP, the ability to generate a useful forecast at the part number level remains challenging for the

demand planning team. A forecast at this level of detail negates the variability-reduction benefits achieved by the ATA part family strategy in the first place.

However, the ATA part family forecast generated by the demand planning team is useful to Spares. The demand forecast generated by ADPP will contain scrap rates and quantities for ATA part families. *As a result, the Spares organization gains useful information from the forecast generated by the Aftermarket Demand Planning Process in terms of total scrap volumes by ATA part family.* Armed with the total scrap replacement volumes generated by the Engine Centers and the part repair facilities, Spares can anticipate scrap replacement requirements and adjust its inventory accordingly. Managers in the Spares organization are receptive to the forecast information at the ATA level, citing their belief that accurate forecasts of scrap replacement volumes by ATA part family is better than poor scrap forecasts at the individual part number level.

Future phases of the ADPP will strive to generate scrap forecasts at the level of detail required by the Spares organization. These methods for generating more detailed scrap replacement forecasts, which include part number probability analyses within part families, are discussed in Chapter 8. For Phase 1 and Phase 2, the demand forecast based on ATA part families is not only necessary to reduce part number variability, but it is also useful to organizations such as Spares even though it is not detailed enough to fulfill every requirement.

### **5.5.3 The Basis for Identifying Exceptions in the ATA Part Family Aggregation**

The demand planning team developed a process to identify and address exceptions in the ATA part family aggregation strategy. The exception cases identified by the demand planning team include exceptions based on the following:

- Dissimilar parts requiring different repair processes and different tracking metrics that are listed under the same ATA code in the Pratt Engine Manuals.
- Similar parts located in separate engine modules or different stages that are listed under the same ATA code in the Pratt Engine Manuals.

These exceptions are explained below.

A problem with the ATA coding structure is that it is a linear, two-dimensional system that catalogues part locations on a three-dimensional engine. As a result, multiple parts within an engine can, and often do, share the same ATA code because they share the same relative linear position within an engine. In cases like the PW2000 2<sup>nd</sup> stage turbine blades, the fact that multiple parts share the same ATA code (sixty-four 2<sup>nd</sup> stage turbine blades on the PW2000 share the same ATA code) does not pose a problem because the parts are nearly identical in structure and are repaired using the exact same process. All sixty-four blades travel through the same repair lines at the same part repair facility, and all have nearly identical repair and/or replacement costs and lead times.

However, a problem arises when fundamentally dissimilar parts share the same ATA code. Parts that are fundamentally dissimilar often require different repair processes from different component repair facilities. Also, these fundamentally different parts are tracked differently throughout the repair process in terms of lead times, repair versus replacement costs, and failure analysis studies. In these situations, the Aftermarket demand planning team requires a method for differentiating these parts that share a common ATA code.

An example of fundamentally dissimilar parts that share the same ATA involves fan cases and tubes. In certain Pratt & Whitney engines, the titanium casing that protects the engine fan blades shares the same ATA code as some of the external tubing that transfers excess air or lubricating oil across engine modules. The fan case is a large engine part, in some engines it can be 112 inches in diameter, that incurs significant repair or replacement costs in the unlikely event that the fan case is damaged. Repairing a fan case requires highly skilled mechanical and technical inspectors, and the item is tracked closely by Pratt repair/spare parts, quality control, and engineering organizations to identify and correct trends in failure rates.

In contrast, the small tubing on the outside of an engine requires more frequent service, but it incurs minimal cost compared to the overall cost of an engine overhaul. These two items are repaired differently, by different repair facilities and repair processes with significantly different costs and lead times. In this example, it is clear that the fan case and the tubing should not be grouped together under the same ATA part family due to their significant differences in repair procedures and repair/scrap costs and lead times.

A second case that requires exception to the ATA part family criteria involves similar parts that appear in several different stages of an engine yet share the same ATA code.

An example of this occurs in the ATA coding structure for the V2500 engine. In the V2500 engine manuals, several stages of compressor and turbine blades are listed under the same ATA code. For instance, the compressor blades on the fifth, sixth, and seventh stage compressor for the V2500 all share the same ATA code. It is feasible that all compressor blades on the V2500 engine, regardless of the stage, are similar in structure and are repaired using the same repair process. However, certain organizations within Pratt, such as the Flight Management Program, Engineering, and Spares, requires that blades from different stages be tracked separately for failure rate analysis, life cycle analysis, and replacement cost analysis. Therefore, the demand planning team separates these similar parts by exception to the ATA part family framework.

#### **5.5.4 The ATA Suffix System: A Method to Account for ATA Part Family Exceptions.**

The Aftermarket demand planning team utilizes a simple ATA suffix system to delineate exceptions as described in the previous section. Under this system, parts that meet the criteria for exception to the ATA part family framework are separated by the manual addition of an alphabetic suffix to the ATA part family code. In the example of the fan case and the tubing, if both are listed in the engine manual under the same hypothetical ATA code, “72-32-00”, then the demand planning team would assign the ATA part family exception code “72-32-00-A” to all fan case part numbers and “72-32-00-B” to all tubing part numbers. Each ATA part family exception is assigned a separate standardized part family name and part family quantity. In the fan case and tubing



example, the ATA part family for the fan case would have a total quantity of one while the ATA part family for the tubing could have a quantity as high as 30 or 40, depending on the engine model.

Therefore, all part numbers within an engine configuration grouping (or static engine template) can be grouped according to their ATA code, with exceptions delineated by an alphabetic suffix added manually by the Aftermarket demand planning team. This is the basis for the part configuration aggregation strategy used by the demand planning team to construct static engine templates, a process that is described in Chapter 6.

## **6 Chapter 6. The Process for Using ERP Data to Construct Engine Templates and Typical Engine Part Disposition Profiles.**

The engine template, along with the Typical Engine Part Disposition (TEPD) profiles, represent the cornerstone of the Aftermarket Demand Planning Process. This chapter describes the process for constructing a complete engine template, including both the static engine template portion and the corresponding TEPD profiles, using ERP data from Pratt Engine Centers.

### **6.1 Constructing a Static Engine Template**

An example of a completed static engine template appears in Figure 6.1. As stated earlier, a static template resembles a bill of material, or a detailed parts list, for a given engine model grouping. Using the ATA part family aggregation criteria described in Chapter 5, along with the ATA suffix for exceptions, the demand planning team can create static engine templates for every engine configuration in the Pratt & Whitney Engine Fleet. The static engine template represents a specific engine configuration grouping, and is used as a basis to populate the TEPD profiles, which will be described later in this chapter.

The first step in constructing a static engine template is to identify the engine configuration grouping that a specific static engine template will represent, as described in Section 5.2.1 and 5.2.2. For Phase 1, eleven static engine templates represent the 5 engine families depicted in Figure 5.1. For future phases of the ADPP, the demand planning team will construct enough static engine templates to represent every engine in the Pratt & Whitney Engine Fleet. As a result of these pre-determined relationships between engine serial numbers and static engine templates, any future engine shop visit can be identified by engine serial number and automatically grouped according to the static engine template that represents it.

The next step in constructing a static engine template is to extract a bill of material from the ERP database for all engines within a defined static engine configuration grouping.

The ERP data is extracted based on the engine serial number and the entire history of part disposition data of that engine denoted by part number. In order to extract a complete bill of material for an engine, the demand planning team extracted data only from heavy overhauls within an engine configuration grouping. Of the possible engine worksopes, a heavy engine overhaul generates the largest and most comprehensive part demand. Therefore, by extracting a part demand list for all heavy engine overhauls, the demand planning team can capture a comprehensive list of part numbers that could possibly be repaired or scrapped from a given engine configuration. This raw bill of materials for all engine serial numbers within an engine configuration grouping, listed by part number, represents the entire part demand history for the particular engine configuration grouping.

The last step in constructing a static engine template is to group the comprehensive part number information into ATA part families. Using the ATA code aggregation strategy described in Chapter 4, the demand planning team accumulates all ERP data associated by part number into ATA part families. The result is a comprehensive ATA part family listing for an engine configuration grouping.

## **6.2 The Reduction of Variability Achieved by Static Engine Templates**

It is important to note that this complete part demand history of an engine configuration grouping only depicts parts that are recorded in the ERP database at the Engine Center. As a result, extraneous parts that are not dispositioned during an engine overhaul are excluded from the final part demand history of an engine configuration grouping. The exclusion of extraneous parts further eliminates variability in the ADPP.

An engine contains thousands of individual parts. Many of these parts, however, are not repaired during an engine overhaul. For instance, an engine contains items called “kit and bin” that includes screws, cotter pins, spacers, packing material, nuts, bolts, and similar common items. The demand data for “kit and bin” items represents extraneous information for Aftermarket repair facilities because a repair facility does not repair these items. Rather, these items are either dispositioned as “serviceable” or they are replaced in bulk by the Spares organization. By excluding these items, the ADPP does not attempt

to forecast the chaotic nature of “kit and bin” part demand because it is unnecessary. Also, by excluding these parts from the static engine template, the total number of parts that constitute an engine is significantly reduced.

### 6.3 Examining A Completed Static Engine Template

An excerpt from a completed static engine template for the PW2000 engine family appears in Figure 6.1. The full-length version of the static engine template for the PW2000 engine family contains approximately 400 distinct ATA part families.

ATA Group	ATA Description	ATA UPE	Part #	Module
72-32-10	No. 1 Bearing Front Support Assembly	1	1A9111	LPC Drive Shaft
72-32-10	No. 1 Bearing Front Support Assembly	1	1B2789	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B2746	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B2747	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B2748	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B2749	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B5128	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B5129	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B5130	LPC Drive Shaft
72-32-11	No. 1 Bearing	1	1B5131	LPC Drive Shaft
72-32-12	No. 1 Bearing Seal Seat	1	1A9711	LPC Drive Shaft
72-32-13	No. 1 Bearing Shouldered Stud	20	1B2809	LPC Drive Shaft
72-32-14	No. 1 Bearing Seal Support Assembly	1	1B2785	LPC Drive Shaft
72-32-15-A	SEAL ASSY-#1BRG	1	1B5478	LPC Drive Shaft
72-32-15-B	SPRING-HELICAL,COMPRESSION,.496 X	12	1A3065	LPC Drive Shaft
72-32-15-C	SPACER-SLV,BRG FACE SEAL	2	1A3062	LPC Drive Shaft
72-32-16	No. 1 Bearing Seal Ring Holder Assembly	1	1B4297	LPC Drive Shaft
72-32-17	No. 1 Bearing Seal Face Assembly	1	1B5479	LPC Drive Shaft
72-32-25-A	SEAL ASSY-#2&3BRG	1	1A5839	LPC Drive Shaft
72-32-25-A	SEAL ASSY-#2&3BRG	1	1B7865	LPC Drive Shaft
72-32-25-B	SPACER-SLEEVE,BRG FACE SEAL	4	1A3063	LPC Drive Shaft
72-32-25-B	SPACER-SLEEVE,BRG FACE SEAL	4	1B7077	LPC Drive Shaft
72-32-25-B	SPACER-SLEEVE,BRG FACE SEAL	4	1B7866	LPC Drive Shaft
72-32-25-C	SPRING-HELICAL,COMPRESSION,.437X	24	1A3066	LPC Drive Shaft
72-32-25-D	SEAL RING-7.316ODX.1775X.157	1	1A3037	LPC Drive Shaft

**Figure 6.1. Excerpt from a Static Engine Template for the PW2000 engine**

The excerpt in Figure 6.1 is from a Microsoft Excel spreadsheet constructed by the demand planning team. All static engine templates are typically constructed in Excel and

tested for accuracy before they are uploaded into the demand planning database, which is a Microsoft Access front-end system with an Oracle back-end database for Phase 1.

The first two columns of the static engine template are entitled “**ATA Group**” and “**ATA Description.**” The information in these columns is the direct result of the ATA part family aggregation strategy employed by the demand planning team. The “ATA Group” is the ATA code that defines the part family and the “ATA Description” is the *standardized name* assigned to each part number in an ATA part family grouping. Reading down the “ATA Group” column in Figure 6.1, one also notices the ATA part family exceptions denoted by the alphabetical suffixes (“72-32-15-A”, “B”, “C” and “72-32-25-A”, “B”, “C”, “D”). As discussed in Section 4.5.4, these entries illustrate fundamentally dissimilar parts that share the same ATA code in the engine technical publications recorded in the ERP database. The demand planning team recognizes the fundamental difference in the repair process and financial tracking of these parts, and therefore manually assigns the alphabetical suffix to delineate these distinct parts.

The next two columns are entitled “**ATA UPE**” and “**Part #.**” The **UPE**, or **Units Per Engine**, denotes the total number of parts in an ATA part family grouping. To illustrate the “ATA UPE” concept, refer to the example in Section 5.1.1 concerning 2<sup>nd</sup> Stage turbine blades on a PW2000 engine. Despite the possible combinations of twenty different part numbers, every PW2000 engine consists of sixty-four 2<sup>nd</sup> Stage turbine blades. This fixed quantity among all PW2000 engines, sixty-four, represents the **Units Per Engine (UPE)** for this ATA part family. The concept of the ATA UPE is a direct result of the part configuration aggregation strategy employed by the demand planning team.

The “**Part #**” column is a complete list of the distinct part numbers that constitutes an ATA part family. Every possible part number for a specific engine configuration grouping is captured in the static engine template. This complete list of part numbers allows end-users of the ADPP to quickly convert part numbers into ATA part families.

Also, this complete list of part numbers can be used by Spares to develop part number demand profiles, which is discussed further in Chapter 8.

It should be emphasized that part numbers appear only once in the “Part #” column of a static template. A single part number cannot belong to two different part families on the same template.

The final column is entitled “**Module**”, which denotes the engine module that contains the corresponding ATA part family. In this example, all the ATA part families shown in Figure 6.1 are located in the **Low Pressure Compressor (LPC) Drive Shaft** module in the PW2000 engine.

#### **6.4 An Example of the Data Displayed in a Static Engine Template**

To illustrate the relation between all the columns on a static engine template, refer to the eight entries with the ATA code “**72-32-11**” (in the “ATA Group” column) in Figure 5.1. The standard name assigned to this ATA part family is “**No. 1 Bearing.**” Looking down the “ATA UPE” column for this ATA part family, one notices that the UPE is equal to 1. The UPE quantity signifies that there is only one No. 1 Bearing on every PW2000 engine.

However, looking down the “Part #” column, one notices that there are 8 different part numbers in the Pratt & Whitney inventory that can function as the No. 1 Bearing on a PW2000 engine. The list of part numbers represents the comprehensive list of part numbers that are recorded in the ERP system for this engine configuration grouping. These part numbers are essentially interchangeable, and can be assumed at this point to have an equal probability of appearing in a PW2000 engine inducted for overhaul. The probability that certain parts may appear on engines more frequently than other parts will be explored in Chapter 8.

And finally, looking down the last column, one notices that the No. 1 Bearing is located in the Low Pressure Compressor Drive Shaft module of the PW2000 engine.

Similarly, the entire data set for the PW2000 engine configuration is defined by the over 400 part family groupings in the static engine template. Once the static portion of the engine template is complete, the demand planning team can focus on constructing the dynamic portion of the engine template.

The effect of the ATA-based part aggregation strategy is that approximately 4500 individual parts on a PW2000 engine can be defined by a little more than 400 ATA part families. This order-of-magnitude reduction in the amount of information required to define the part configuration of an engine further reduces the demand variability in the historical ERP data. Using this aggregation strategy, one can analyze demand trends for 400 ATA part families instead of trying to identify historical demand trends for 4500 individual parts on a PW2000 engine. The higher level of aggregation makes ATA part family demand trends more consistent than part number demand trends, and therefore easier to identify.

### **6.5 The Dynamic Portion of the Engine Template: The TEPD**

The dynamic portion of the engine template builds upon the framework constructed in the static portion and forms the final critical piece of a completed engine template. The dynamic portion is termed “dynamic” because unlike the static ATA part family listing, the dynamic portion contains historical ERP disposition data that requires regular updates. The dynamic portion of the engine template depicts the historical disposition percentages of a particular ATA part family extracted from the ERP database. The dynamic portion of an engine template forms a Typical Engine Part Disposition (TEPD) profile.

As discussed in Section 2.4.2, once a part is removed from an engine and inspected in a Pratt & Whitney Engine Center, it is assigned one of five disposition codes: S, E, I, Rb, or Rv. These codes, along with other information, are recorded in the ERP database for every individual part number inspected in an overhauled engine. The entire list of individual part dispositions recorded in ERP can be accumulated and grouped according

to the ATA part family framework utilized by the static engine template. With a large sample size of overhauled engines within a specific static engine model grouping, a comprehensive historical part family disposition profile can be calculated.

An excerpt from a completed engine template for a PW2000 engine appears in Figure 6.2. The completed template contains the columns discussed in the construction of a static engine template, plus five additional columns representing the five possible part disposition codes. Notice that the part number list that appeared in the static engine template (Figure 6.1) has been compressed such that each line-entry in the completed template represents only one distinct ATA part family. This compression of part data enhances readability of the template and allows users to focus on the ATA part family patterns instead of patterns among individual part numbers.

ATA Group	ATA Description	ATA UPE	Part #	Rb*	Rv*	E*	I*	S*
72-32-10	No. 1 Bearing Front Support Assembly	1	All	50.00%	0.00%	0.00%	25.00%	25.00%
72-32-11	No. 1 Bearing	1	All	50.00%	0.00%	0.00%	0.00%	50.00%
72-32-12	No. 1 Bearing Seal Seat	1	All	75.00%	0.00%	0.00%	25.00%	0.00%
<b>72-32-13</b>	<b>No. 1 Bearing Shouldered Stud</b>	<b>20</b>	<b>All</b>	<b>25.00%</b>	<b>25.00%</b>	<b>25.00%</b>	<b>25.00%</b>	<b>0.00%</b>
72-32-14	No. 1 Bearing Seal Support Assembly	1	All	0.00%	0.00%	0.00%	75.00%	25.00%
72-32-15-A	SEAL ASSY-#1BRG	1	All	0.00%	0.00%	0.00%	25.00%	75.00%
72-32-15-B	SPRING-HELICAL,COMPRESSION,496 X	12	All	33.30%	0.00%	33.30%	33.30%	0.00%
72-32-15-C	SPACER-SLV,BRG FACE SEAL	2	All	0.00%	0.00%	50.00%	25.00%	25.00%
72-32-16	No. 1 Bearing Seal Ring Holder Assembly	1	All	0.00%	0.00%	50.00%	50.00%	0.00%
72-32-17	No. 1 Bearing Seal Face Assembly	1	All	50.00%	0.00%	0.00%	50.00%	0.00%
72-32-25-A	SEAL ASSY-#2&3BRG	1	All	25.00%	25.00%	25.00%	0.00%	25.00%
72-32-25-B	SPACER-SLEEVE,BRG FACE SEAL	4	All	66.70%	0.00%	0.00%	33.30%	0.00%
72-32-25-C	SPRING-HELICAL,COMPRESSION,437X	24	All	25.00%	0.00%	25.00%	25.00%	25.00%
72-32-25-D	SEAL RING-7.316ODX.1775X.157	1	All	0.00%	50.00%	0.00%	0.00%	50.00%

\* Percentages are artificially generated and do not reflect actual PW2000 ERP disposition data. Percentages are for illustrative purposes only.

**Figure 6.2. Excerpt from a Completed Engine Template for a PW2000 engine.**

It should be emphasized that the comprehensive list of part numbers that constitute a given ATA part family is still captured in the completed template. All possible part numbers for a specific ATA part family are simply compressed into one cell on the



spreadsheet. The complete list of part numbers is represented artificially by the word “All” that appears in the “Part #” column.

Under each disposition column, there appears a percentage that corresponds to each row of ATA part families. The disposition percentages that appear in Figure 6.2 are artificially generated for the purposes of illustration. The numbers do not represent actual disposition data. The disposition percentages are normally calculated using the entire history of PW2000 heavy overhauls recorded in the ERP database at Cheshire Engine Center.

### **6.5.1 The Information Displayed on a Complete Engine Template**

To highlight the information that is contained on a complete template, refer to the row of data grouped by the ATA code “72-32-13” (in boldface) in Figure 6.2. The UPE of this part family is twenty, which signifies that there are twenty “No. 1 Bearing Shouldered Studs” on a PW2000 engine. The comprehensive list of individual part numbers that constitute the part family is compressed in the “Part #” column. The disposition percentages signify that, for all PW2000 heavy engine overhauls recorded in the ERP database at Cheshire, the following patterns were identified by the demand planning team.

- 25% of all No. 1 Bearing Shouldered Studs were scrapped at the Engine Center, (Rb).
- 25% were scrapped at the part repair facility, (Rv).
- 25% were repaired by the external part repair facility, (E).
- 25% were repaired in the Engine Center, (I).
- 0% were deemed serviceable.

Additional information, such as the total number of PW2000 heavy overhauls in the Cheshire ERP database (engine sample size) and total number of parts dispositioned for each ATA part family (part sample size), is included on the complete engine template, although this information is not shown explicitly in Figure 6.2. As Cheshire performs more PW2000 heavy overhauls, the sample size of the information will increase, and the

disposition percentages can change with the additional information. Therefore, the disposition percentages are refreshed once a month from the Cheshire ERP database.

### **6.5.2 How Disposition Codes are Mined and Calculated**

Disposition histories are calculated from raw ERP transactional data. For Phase 1 of the ADPP, the disposition codes are mined strictly from Cheshire ERP data. The computer algorithms, or queries, extract ERP disposition data according to three primary criteria:

- Engine model (as defined by the static engine template)
- Workscope: Heavy Overhaul Only (Phase 1)
- Part number (as listed on the static engine template)

The demand planning data-mining queries essentially extract all disposition codes by part number from historical ERP data for all heavy overhauls within a specified group of engine serial numbers dictated by the static engine configuration grouping. A secondary computer algorithm cleanses this extracted disposition data, and aggregates the data according to the ATA part family framework identified in the static engine template. The result is the disposition percentages that are depicted in Figure 6.2.

A complete template, with both a static and dynamic portion, represents a Typical Engine Part Disposition (TEPD) profile based on the data filtering criteria used to extract ERP data. As discussed previously in Section 5.3, a TEPD profile can be constructed to represent a wide range of demand scenarios. In Figure 6.2, the primary data-filtering criteria used to generate the TEPD profile includes data from all heavy overhauls performed at Cheshire for PW2000 engines.

### **6.5.3 “What-if” Analysis Using the Typical Engine Part Disposition Profile**

The ability to construct TEPD profiles for different demand scenarios is also useful for “what-if” analysis. For instance, if a major airline is considering moving their engine overhaul operations “in-house”, thereby no longer shipping engines to Pratt for overhaul, the demand planning team can construct a TEPD profile to determine the effect of this event on Pratt Engine Centers. The demand planning team can develop historical repair and scrap ratios for this specific airline, along with the average number of overhauls

performed by Pratt for this airline in an average year, and determine how much repair volume would be lost in this scenario.

Almost any “what-if” scenario can be analyzed based upon its predicted effect on historical part demand. Examples of these scenarios are discussed in Section 8.1.2.

The important point is that the TEPD profiles can be constructed quickly and with minimal manual effort. The data mining logic is flexible enough to accept multiple data filtering criteria and can extract data into a TEPD profile quickly and automatically. The result is a verifiable, accurate summary of historical data that can be analyzed, along with assumptions, and can provide a basis for decision-making by management.

The next chapter discusses how this completed template is used to generate an Aftermarket demand forecast. However, before we discuss how the templates are utilized, we must first describe the cleansing logic invented by the demand planning team to cleanse raw ERP disposition information.

## **6.6 The Challenge Posed by Discrepancies in the Raw ERP Data**

The process for extracting historical repair and scrap disposition ratios from ERP data is not a straightforward process. Raw ERP data contains errors and natural discrepancies, termed “dirty” data, that renders it almost useless in its raw form. The Aftermarket demand planning team spent considerable time analyzing raw ERP data, identifying discrepancies, understanding the underlying causes for those discrepancies, and developing cleansing logic to rid the extracted data of those discrepancies.

### **6.6.1 Identifying Discrepancies in the Raw ERP Data**

The first challenge the demand planning team faced was identifying discrepancies in the raw ERP data. The discrepancies were apparent in the disposition ratios calculated from the raw data. For example, assume a certain engine has an ATA Part Family “A” with a UPE (Units Per Engine) of 20. For each engine in the ERP data, the demand planning team would expect to find twenty separate part dispositions for Part Family “A”, which corresponds to the UPE. However, in many cases, the demand planning team would

discover that the number of parts dispositioned for this Part Family “A” either exceeded twenty or was less than twenty. Stated another way, the raw ERP data suggests one of two things: either certain parts in this part family were not inspected nor dispositioned, or that the number of parts inspected and dispositioned on this engine exceeds the actual part quantity on the engine.

This discrepancy was identified for a significant number of ATA part families across almost every engine configuration grouping. To explain this discrepancy, the demand planning team examined three primary possibilities:

1. The engines represented by a single engine configuration grouping are in fact fundamentally different, and the demand planning team must create more static templates and reclassify engines to account for these differences.
2. Certain UPE (Units Per Engine) values on the static engine templates are incorrect.
3. The ERP data is “dirty.”

The demand planning team reviewed the static engine templates and corrected minor mistakes in the UPE and in the engine configuration groupings, thus eliminating possibilities 1 and 2 as the primary source of the discrepancies. Despite the elimination of possibilities 1 and 2, a significant number of discrepancies still existed in the raw ERP data. Therefore, the demand planning team focused their analysis on the ERP data to explain the data discrepancies.

### **6.6.2 Identifying the Sources for Discrepancies in the Raw ERP Data**

To investigate the sources for the discrepancies identified in the ERP data, the demand planning team sought the help of ERP operators and the Cheshire Engine Center management. The result of our investigation yielded three primary causes for these observed discrepancies.

1. Data-entry errors due to inexperienced operators.
2. The tendency of data-entry operators to omit “Serviceable” dispositions from the ERP record.

3. Multiple part dispositions due to the natural progression of a part through a repair process.

The first cause we identified was data-entry errors due to inexperienced operators. The ERP system had only been in place for approximately one year at the time the demand planning team began extracting data, so operators tasked with ERP data-entry were still experiencing a learning curve. The errors attributed to the operator learning curve were relatively limited, and therefore not significant. Management at the Cheshire Engine Center had quickly identified these data-entry errors and corrected these problems with additional operator training and the implementation of more restrictive data entry options in the ERP user-interface.

A second source of the observed discrepancies is due to the tendency of data-entry operators to omit “serviceable” disposition entries in ERP. Parts that are inspected and deemed “serviceable” incur very little cost and time compared to the overall costs and turn times involved in an engine overhaul. In most cases, “serviceable” parts can be stored “as-is” at the Engine Center until they are needed for final engine re-assembly. Since these parts incur minimal cost and time, operators tend to omit “serviceable” disposition records from ERP.

A contributing factor in this observed trend is that the ERP system is much less restrictive concerning the entry procedures of “serviceable” parts, so these transactions tend to be omitted more readily. The management at Cheshire is addressing this trend and is training operators to record all dispositions for every part.

A third cause of discrepancies in the ERP data is due to the natural progression of a part through the repair process. A single part that progresses through a repair process can be dispositioned several times, thus creating multiple ERP disposition records for a single part.

For example, a certain part can be inspected and dispositioned for internal repair (“I”) at the Engine Center. However, if the internal repair line is backlogged, the same part may be re-dispositioned as “E” and shipped to a part repair facility for external repair. The same part, upon the inspection at the part repair facility, may be dispositioned as scrap (“Rv”) and hence require a replacement part. (Or, another possibility is that the part is further damaged during the repair process at the part repair facility, and dispositioned as scrap.)

For the above example, the part is dispositioned three times in the repair process: I, E, and Rv. Since ERP is a historical record of all operational transactions, all three dispositions associated with this single part are recorded in the ERP database. This natural progression of a part through a repair process explains the observed discrepancy in the ERP data when the number of dispositions exceeds the number of parts on an engine.

Identifying discrepancies in the ERP data is essential. However, once these discrepancies are identified, the crucial task is developing a method to cleanse the data of these discrepancies and extract the most accurate information. The data cleansing technique employed by the demand planning team is introduced in the following section.

### **6.7 The REIS Hierarchy: Cleansing Raw ERP Data**

The challenge facing the demand planning team is to determine the ultimate disposition of a part when there are obvious discrepancies in the ERP data. The resulting cleansing logic that eliminated these discrepancies in the Cheshire ERP raw data is called the “**REIS**” **hierarchy** (pronounced “Rice”). The letters in the REIS acronym correspond to the possible disposition codes: Scrap (**Rb** or **Rv**), External repair (**E**), Internal repair (**I**), and Serviceable (**S**). The use of the term “hierarchy” signifies an order of precedence in the REIS acronym, with “R” signifying the highest level of precedence and “S” signifying the lowest level of precedence. The REIS hierarchy quickly determines the single, ultimate disposition of a part, regardless of how many dispositions appear in the ERP database.

The result of this cleansing logic is that the number of part dispositions extracted from ERP equals the number of parts for every ATA part family on an engine. The REIS hierarchy effectively eliminates discrepancies in the number of part dispositions for a specific ATA part family. The REIS hierarchy is based on assumptions about the observed physical reality of a part flow through a repair process. Also, although the REIS hierarchy was developed to cleanse Cheshire ERP data, the demand planning team believes this hierarchy will apply to similar ERP data from all the Pratt & Whitney Engine Centers.

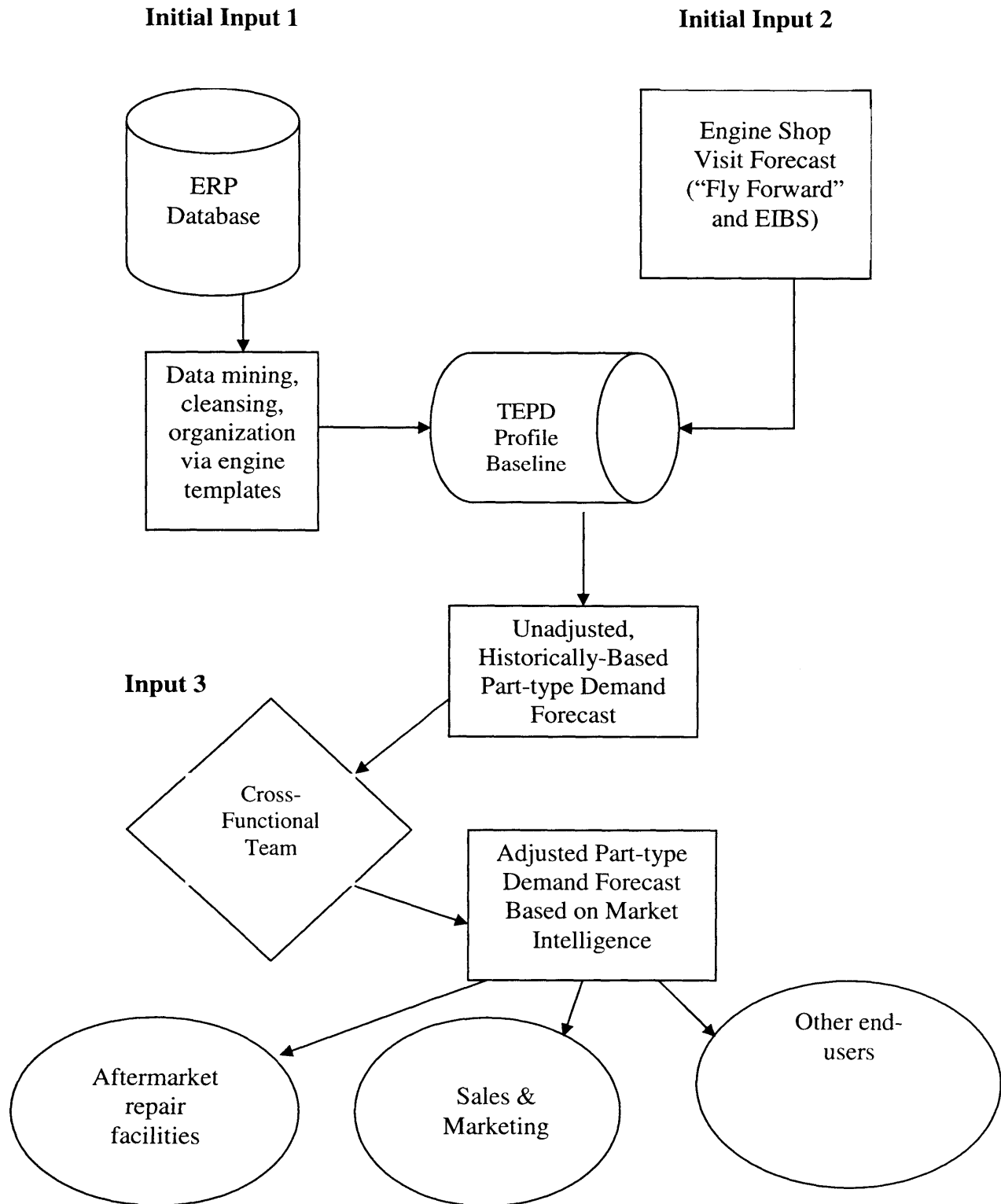
## **7 Chapter 7. The Aftermarket Demand Planning Process**

The Aftermarket Demand Planning Process (ADPP) is the business process that converts an engine shop visit forecast, or an engine induction schedule, into a part-type demand forecast using the completed engine templates described in Chapter 6. This chapter presents an overview of the Aftermarket Demand Planning Process, with emphasis on the Phase 1 implementation.

### **7.1 The Aftermarket Demand Planning Process Flowchart**

Figure 7.1 depicts a simplified process flowchart for Phase 1 of the Aftermarket Demand Planning Process.





**Figure 7.1. ADPP Flowchart for Phase 1.**

The following sections describes the steps in the process.

## **7.2 The Initial Inputs into the Aftermarket Demand Planning Process**

The Aftermarket Demand Planning Process requires two initial inputs in order to produce a part-type demand forecast: an engine shop visit forecast (or engine induction schedule), and a standardized data source from which to identify historical part-type demand patterns. The ADPP combines these two inputs through a conversion process that will ultimately produce a part-type demand forecast for all Pratt & Whitney repair facilities worldwide. It is important to note that the two initial inputs described in this section are not the only inputs into the process. Other inputs involve manual manipulation of the historically based forecast to account for known future events. These inputs will also be discussed in this chapter.

### **7.2.1 The First Initial Input: The Standard Data Source**

The standard historical data source for internal demand, which is the scope of Phase 1, is the ERP database that is being implemented in all Pratt & Whitney Aftermarket repair facilities. The historical ERP data is mined, cleansed, and aggregated into complete engine templates that represent Typical Engine Part Disposition (TEPD) profiles as described in Chapter 6. The completed engine templates are the basis for the ADPP and represent the first initial input into the process.

Identifying the standard historical data source for external demand is the challenge that faces the demand planning team in Phase 2 and beyond. The demand planning team is examining options for gathering historical repair data from external engine centers. The challenges involved in gathering external demand are explored further in Chapter 8.

It is important to note that the ADPP is flexible enough to accept data from a wide range of data sources. For Phase 1, the demand planning team has focused on developing data mining logic for internal ERP systems employed in Pratt & Whitney Aftermarket repair facilities. However, the demand planning team is prepared to expand and adapt the existing data mining logic in order to extract the necessary information from whatever external demand data source is identified for Phase 2 and beyond. Similar to Phase 1

data mining efforts, the adapted data mining logic will extract external data to populate the TEPD profiles for external demand, based on the same criteria introduced previously in Section 5.3.

### **7.2.2 The Second Initial Input: An Engine Shop Visit Forecast**

The second initial input into the ADPP is an engine shop visit forecast. For Phase 1, the internal engine shop visit forecast takes the form of an engine induction schedule, which is generated by the **Engine Induction Booking System**, or **EIBS** (pronounced “E-Biz”). EIBS is an internal system that currently generates an engine induction schedule for Pratt & Whitney Engine Centers, delineated by engine model, by customer, by engine workscope, by month, and by Engine Center. The engine induction schedule depicts future engine overhauls that are scheduled (“booked”) and engine overhauls that are not yet scheduled but are highly likely. EIBS generates this forecast for both Pratt & Whitney engines and competitor engines that are scheduled for service at internal Pratt & Whitney Engine Centers.

The internal engine induction schedule generated by EIBS is sufficiently accurate for up to three months in the future, and useful for engine overhauls up to one year in the future. Since EIBS has only recently been implemented in Pratt & Whitney Aftermarket Services, the rate of decay in forecasting accuracy for EIBS from a three-month forecast to a one-year forecast has not yet been fully calculated. The demand planning team, along with other members of Aftermarket Services, is analyzing the accuracy of EIBS and will continue to improve the system.

For Phase 2, the ADPP will use EBIS as well as outputs from the “Fly Forward” initiative, which will provide both an internal and external engine shop visit forecast. The worldwide engine shop visit forecast generated by the “Fly Forward” initiative will enable the ADPP to convert this data into a worldwide part-type demand forecast. The goal of the “Fly Forward” initiative is to generate this forecast for 18 months into the future. At the time this thesis is written, “Fly Forward” is currently under development at Pratt & Whitney.

### 7.3 The Method for Combining the Two Initial Process Inputs

The engine shop visit forecast is converted into a part demand forecast using the engine templates created from historical ERP demand data. The complete set of static engine templates, which represent all engines in the engine shop visit forecast, converts a set of engines into a complete listing of all corresponding ATA part families. Next, the TEPD profiles associated with these static engine templates depict the historical ERP repair and scrap ratios for each ATA part family. The historical part demand trends depicted by the TEPD profiles are used to predict future part demand trends based on the number of expected future engine inductions.

The following example illustrates how this is accomplished by examining the process of generating a part demand forecast for a single engine model, with a specific workscope, for a single engine center. Using this simplified example of the process is useful in understanding how the process works, and will aid in the understanding of how the process is expanded to generate a worldwide part demand forecast.

For this example, assume that the demand planning team intends to generate a part-type demand forecast for the Cheshire Engine Center. The part-type demand forecast in this hypothetical scenario will focus solely on part demand generated by PW2000 engines undergoing heavy overhauls at Cheshire within the next twelve months.

Refer to the engine template excerpt for the PW2000 engine as shown in Figure 6.2. A copy of Figure 6.2 is shown below and re-numbered as Figure 7.2.

ATA Group	ATA Description	ATA UPE	Part #	Rb*	Rv*	E*	I*	S*
72-32-10	No. 1 Bearing Front Support Assembly	1	All	50.00%	0.00%	0.00%	25.00%	25.00%
72-32-11	No. 1 Bearing	1	All	50.00%	0.00%	0.00%	0.00%	50.00%
72-32-12	No. 1 Bearing Seal Seat	1	All	75.00%	0.00%	0.00%	25.00%	0.00%
<b>72-32-13</b>	<b>No. 1 Bearing Shouldered Stud</b>	<b>20</b>	<b>All</b>	<b>25.00%</b>	<b>25.00%</b>	<b>25.00%</b>	<b>25.00%</b>	<b>0.00%</b>
72-32-14	No. 1 Bearing Seal Support Assembly	1	All	0.00%	0.00%	0.00%	75.00%	25.00%
72-32-15-A	SEAL ASSY-#1BRG	1	All	0.00%	0.00%	0.00%	25.00%	75.00%
72-32-15-B	SPRING-HELICAL,COMPRESSION,.496 X	12	All	33.30%	0.00%	33.30%	33.30%	0.00%
72-32-15-C	SPACER-SLV,BRG FACE SEAL	2	All	0.00%	0.00%	50.00%	25.00%	25.00%
72-32-16	No. 1 Bearing Seal Ring Holder Assembly	1	All	0.00%	0.00%	50.00%	50.00%	0.00%
72-32-17	No. 1 Bearing Seal Face Assembly	1	All	50.00%	0.00%	0.00%	50.00%	0.00%
72-32-25-A	SEAL ASSY-#2&3BRG	1	All	25.00%	25.00%	25.00%	0.00%	25.00%
72-32-25-B	SPACER-SLEEVE,BRG FACE SEAL	4	All	66.70%	0.00%	0.00%	33.30%	0.00%
72-32-25-C	SPRING-HELICAL,COMPRESSION,.437X	24	All	25.00%	0.00%	25.00%	25.00%	25.00%
72-32-25-D	SEAL RING-7.316ODX.1775X.157	1	All	0.00%	50.00%	0.00%	0.00%	50.00%

\* Percentages are artificially generated and do not reflect actual PW2000 ERP disposition data.  
Percentages are for illustrative purposes only.

### Figure 7.2. Excerpt from a Completed Engine Template for a PW2000 engine.

It is important to emphasize that the excerpt of the PW2000 engine template shown in Figure 7.2 depicts a small sample of the over 400 ATA part families that constitute a complete PW2000 engine template.

Assume that the disposition percentages shown in Figure 7.2 reflect all historical ERP data recorded by Cheshire for previous heavy overhauls of the PW2000 engine. This engine template, or TEPD, with updated historical disposition percentages for every ATA part family grouping in the PW2000 engine, constitutes one initial input to the Aftermarket Demand Planning Process.

#### 7.3.1 Generating the Forecast Based on Historical Data

The second initial input is the engine shop visit forecast for Cheshire over the next twelve months. This forecast currently is generated by EIBS, as described in Section 7.2.2.

“Fly Forward” can also be used as a source for this shop visit forecast once it is completed. For this example, assume that the EIBS forecast indicates that over the next

twelve months, Cheshire will receive two PW2000 engines per month requiring heavy overhauls.

The monthly ATA part family forecast for PW2000 engines at Cheshire is calculated for each ATA part family group using the following formula:

$$\text{ATA Part Family Forecast for a given month} = \text{Number of Engines Inducted in a Given Month} * \text{ATA Units Per Engine (ATA UPE)} * \text{Disposition Percentages for ATA Group}$$

### Equation 7.1. ATA Part Family Demand Forecast Calculation

To illustrate the above calculation, refer to ATA Group “72-32-13” in bold print in Figure 7.2. The **ATA Units Per Engine (ATA UPE)** for this group is 20 and the disposition percentages are 25%, 25%, 25%, 25%, and 0% for the “Rb”, “Rv”, “E”, “I”, and “S” disposition codes respectively. Applying Equation 7.1 to this data, the demand planning team can calculate the demand forecast for this ATA part family for any month in the next twelve months. The calculation below is an example of Equation 7.1 used to calculate the internal scrap volume for ATA part family “72-32-13” from the PW2000 engine:

No. 1 Bearing Shouldered Studs, from PW2000 heavy overhauls, Scrapped at Cheshire next month (Rb percentage from Figure 7.2 = 25%, UPE = 20 parts/engine):

$$Rb = (2 \text{ Engines/month}) * (20 \text{ parts/engine}) * 0.25 = 10 \text{ parts/month}$$

This same calculation can be applied using all disposition percentages for the entire list of ATA part families on the PW2000 engine template.

### 7.3.2 Forecast Content Tailored for Information Requirements

Continuing with the same PW2000 example, it is important at this point to consider the content of the demand forecast that will be generated for the Cheshire Engine Center. To

generalize, the content of the demand forecast generated for a certain repair facility depends upon the specific information requirements of that facility. In the case of an Engine Center, managers of these facilities do not require forecasts for the number of parts that will be externally repaired, or the number of parts determined to be serviceable. Instead, Cheshire management wants to know the following information:

- Total volume of parts (by part-type or part family) Cheshire will inspect/induct in a given month
- Total number of parts, by part type, that Cheshire will repair in a given month (parts coded “I”)
- Total number of parts, by part type, that will be scrapped internally and externally (number of parts coded “Rb” + number of parts coded “Rv” )

As a system integrator for the engine overhaul, it is the responsibility of the Engine Center to order all scrap replacement parts. Part repair facilities order replacement parts through the Engine Center, which in turn orders replacement parts from the Spares organization.

*Therefore, from the perspective of the Engine Center, the internal demand that an Engine Center absorbs in a given month can be described solely by the total scrap volumes and internal repair volumes.*

The external part repair facilities, on the other hand, are concerned with the total number of parts they will receive in a given month and the total number of parts that will ultimately require repair. A manager at an external Part repair facility requires accurate information about the total volume of parts, by part-type, that will be inducted and repaired at the Part repair facility in a given month (the parts coded “Rv” and “E”).

On the web-based ADPP, the part repair facilities have the option of viewing a forecast for the total number of parts shipped from an Engine Center (“Rv” and “E” parts), or viewing only the forecasted repair volumes (parts coded “E”).

#### 7.4 The Third Input: The Cross-Functional Team

The demand planning team can use Equation 6.1 to develop a monthly demand forecast, by ATA part family, for all PW2000 overhauls at Cheshire. Figure 6.3 in the next section depicts the final forecast report content.

However, the accuracy of a forecast based solely on historical information is vulnerable to future demand disturbances that are non-typical and therefore not captured in the historical data. In their book, *Factory Physics*, Wallace Hopp and Mark Spearman explain:

*...forecasting is more than a matter of selecting a model and tinkering with its parameters to make it as effective as possible. No model can incorporate all factors that could be relevant in anticipating the future. Therefore, in any forecasting environment, situations will arise in which the forecaster must override the quantitative model with qualitative information.*<sup>19</sup>

Therefore, the demand planning team is developing and implementing a monthly, repeatable process to gather input and market intelligence from a variety of sources within Pratt & Whitney. This cross-functional team will consist of representatives from Sales and Marketing, Engineering, Finance, Spares, Aftermarket Services, and other organizations. The objective of the cross-functional team is to identify known future events that may invalidate historically-based predictions about the future demand patterns, and to determine the effect of these known events on the historically based forecast.

The development of a new repair process is an example of a future event that may result in modifications to the historically-based disposition percentages as shown in Figure 7.2. For this example, assume a new and improved repair process is introduced that can

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<sup>19</sup> Wallace J. Hopp and Mark L. Spearman. *Factory Physics*, 2<sup>nd</sup> ed. (New York: Irwin/McGraw-Hill, 2001); 430.



repair certain parts that historically had to be scrapped due to the limitations in the previous repair process. The historically-based scrap and repair ratios in the TEPD profile for that particular part family would no longer be valid, and representatives within the cross-functional team would have to determine new scrap and repair ratios based upon their cross-functional experience and knowledge of the Aftermarket business.

The adjusted scrap and repair ratios determined by the cross-functional team would be manually entered into the TEPD profiles, which would effectively override the ratios calculated from historical ERP data. However, the calculated ratios from actual ERP data are not deleted. Rather, the historically-based part repair and scrap ratios calculated from ERP data continue to be updated separately from the manually adjusted ratios. The assumptions made in developing the adjusted scrap and repair disposition ratios are documented and the results tested for accuracy, and compared against the accuracy of the original historically-based ERP disposition history over time. With this documentation of assumptions and a thorough forecast accuracy analysis, the cross-functional team can be held accountable for their assumptions, and errors in the forecast can be systematically identified and corrected.

## **7.5 Presenting Dual Forecasts to End-Users**

During Phase 1, the demand planning team is debating how these dual forecasts, which are the unadjusted forecast and the manually adjusted forecast, will be presented to end-users. Some members of Aftermarket Services argue that the demand planning team should present one set of forecast numbers to the end-users, which should be the adjusted forecast. Other members argue that both the adjusted and the unadjusted forecasts should be displayed simultaneously to end-users, with the differences highlighted along with the corresponding assumptions explaining these differences.

At the time this thesis is written, the demand planning team agrees that one forecast should be presented to the end-users. As the cross-functional team becomes more involved in the ADPP, and as the cross-functional team improves their ability to make

accurate assumptions and determine the effect of those assumptions on future demand, the adjusted forecast will most likely be the official ADPP forecast. Until then, the unadjusted forecast will be the official ADPP forecast, based solely upon historical ERP data and an engine shop visit forecast.

The demand planning team is also discussing the feasibility of displaying key statistical metrics to end-users that define the level of the ADPP forecast uncertainty. These statistical metrics may include a standard deviation calculation, a range of minimum and maximum forecasts (outliers), or a confidence interval calculation for each item on the ADPP forecast. While the exact format and content of the statistical metrics are still being developed, the ultimate goal of the demand planning team is to provide end-users with a single, tailored forecast along with the corresponding forecast uncertainty metrics. The forecast uncertainty metrics will allow managers to make more informed decisions based upon the ADPP forecast.

The future role of the cross-functional team, including incorporation of the **Sales and Operations Planning (S&OP)** initiative as a potential source for this cross-functional team, is discussed further in Section 8.3.

## **7.6 The Forecast Results**

Referring back to our example, the demand planning team is now ready to present its part-type demand forecast from PW2000 heavy overhauls over the next twelve months at Cheshire. Figure 7.3 below depicts an excerpt of the ATA part family demand forecast calculation for the PW2000 engine using Equation 7.1. For simplicity, only one month forecast is depicted in Figure 7.3 below. Due to the initial assumption of a constant monthly engine shop visit forecast (2 engines per month over twelve months), the part family demand forecast is constant for every month over the next year. The ATA part families that are listed below are the same as the ATA part families listed in Figure 7.2. Refer to Figure 7.2 for the disposition percentages for these part families.

ATA Group	ATA Description	ATA UPE	# of Engines/ Month*	Total # Parts/ Month	# Parts Rb**	# Parts Rv**	# Parts E **
72-32-10	No. 1 Bearing Front Support Assembly	1	2	2	1	0	0
72-32-11	No. 1 Bearing	1	2	2	1	0	0
72-32-12	No. 1 Bearing Seal Seat	1	2	2	1	0	0
<b>72-32-13</b>	<b>No. 1 Bearing Shouldered Stud</b>	<b>20</b>	<b>2</b>	<b>40</b>	<b>10</b>	<b>10</b>	<b>10</b>
72-32-14	No. 1 Bearing Seal Support Assembly	1	2	2	0	0	0
72-32-15-A	SEAL ASSY-#1BRG	1	2	2	0	0	0
72-32-15-B	SPRING-HELICAL, COMPRESSION, .496 X	12	2	24	8	0	8
72-32-15-C	SPACER-SLV, BRG FACE SEAL	2	2	4	0	0	2
72-32-16	No. 1 Bearing Seal Ring Holder Assembly	1	2	2	0	0	1
72-32-17	No. 1 Bearing Seal Face Assembly	1	2	2	1	0	0
72-32-25-A	SEAL ASSY-#2&3BRG	1	2	2	1	0	1
72-32-25-B	SPACER-SLEEVE, BRG FACE SEAL	4	2	8	5	0	0
72-32-25-C	SPRING-HELICAL, COMPRESSION, .437X	24	2	48	12	0	12
72-32-25-D	SEAL RING-7.316ODX.1775X.157	1	2	2	0	1	0

\* Depicts the number of inductions by month for PW2000 heavy overhauls. Assumed to be constant for twelve month horizon.

\*\* Numbers are rounded to nearest integer.

**Figure 7.3. Excerpt from a Part-Family Demand Forecast for a PW2000 engine.**

The forecast excerpt depicted above is the monthly ATA part-family demand forecast, tailored for Cheshire, due to the engine shop visit forecast of heavy overhauls for the PW2000 engine. While the information in Figure 7.3 represents the actual content of a forecast, the actual report format is organized differently to enhance readability. An example of the actual forecast report format from the ADPP website are depicted in Appendix 1, located at the end of this thesis.

### 7.7 How a Manager at an Engine Overhaul Center Will Use the Demand Forecast

Refer to the ATA part family “72-32-13” in bold print in Figure 7.3. Based on this report, a Cheshire manager would anticipate repairing ten No. 1 Bearing Shouldered Studs per month while scrapping a total of twenty a month for the next 12 months. Assuming that the only demand that Cheshire will experience over the next twelve months is due to PW2000 heavy overhauls, then the Cheshire management can alert

Spares to anticipate orders for twenty No. 1 Bearing Shouldered Studs a month for the next twelve months. The Spares organization, along with the demand planning team, can attempt to determine part-number requirements based upon known probabilities of certain part numbers in certain engines. This option of generating more detailed part number information for Spares is explored in Section 8.1.3.

Furthermore, the Cheshire manager can analyze the capacity of the No. 1 Bearing Shouldered Stud repair line, along with the expected demand of parts that share the same repair line, and determine if Cheshire is over-capacity or under-capacity for this part family. With this information, the manager can take action to proactively correct demand and capacity (including labor) imbalances before they arise. The results of balanced demand and capacity include faster repair turn times, less inventory (replacement parts from Spares), lower costs, and increased customer satisfaction. With a reliable demand forecast with the necessary level of operational details, the managers at Cheshire can create better value for their customers, which in turn will increase demand in the future.

Of course, this example illustrates a very small piece of the actual demand that Cheshire will experience over the next twelve months. Cheshire will surely perform overhauls for multiple engine models with varying worksopes over the next twelve months. To account for this, the scope of the ADPP is increased accordingly, but the basic steps in the ADPP as depicted in Figure 7.1 and illustrated in the simple example above remain fundamentally unchanged. The next section describes how the scope is expanded to capture this complete part demand picture.

## **7.8 Generating Expanded Demand Forecasts**

To generate a forecast for the total part-type demand that a repair facility will experience, the demand planning team will use the same process as described in the previous section. For Phase 1, given a complete internal engine induction forecast for all five Pratt & Whitney Commercial Engine Centers, the demand planning team can generate a complete internal demand forecast.

In order to expand the scope of a forecast to include different engine models and workscopes, the first thing that the demand planning team requires is multiple static engine templates that define all possible engine configurations in the engine shop visit forecast. For Phase 1, the demand planning team constructed eleven static engine templates to represent the five major engine families listed in Figure 5.1. Every engine thrust code included in these five engine families is represented in one of the eleven static engine templates constructed in Phase 1.

Another requirement necessary to generate an expanded demand forecast is a complete set of TEPD profiles to account for the different part-type demand patterns due to variations in workscope, customers, regions, and Engine Centers. As described in Section 5.3, there are several different criteria that can be employed to create a TEPD profile. To generate a complete demand forecast, the demand planning team must construct the appropriate number of TEPD profiles, based upon the appropriate ERP data-filtering criteria.

With the appropriate number and types of TEPD profiles, the demand planning team can convert a comprehensive engine shop visit forecast into a comprehensive part-type demand forecast. The next step involves tailoring this forecast for the different end-users.

## **7.9 Tailoring Expanded Forecasts According to Specific Information Requirements.**

With the ability to construct engine templates and disposition profiles for a wide array of demand variations, the demand planning team can also generate a forecast tailored to meet the specific information requirements of a repair facility. The demand planning team is constructing data tables that allow the ADPP to produce these tailored forecasts.

For Phase 1, the information in these data tables includes:

1. A complete list of products that a repair facility repairs. For Engine Centers, this list contains all engine models and thrust codes that an Engine Center repairs. An Engine Center typically repairs a specific set of engine models, thus they only require information on these specific engine models. For part repair facilities, this list contains all parts that the part repair facility typically repairs. For instance, Connecticut Airfoils Repair Operations (CARO) only repairs airfoils (turbine and stator blades) for a certain set of engine models. *With this information, the demand planning team can tailor a forecast for a repair facility so that only the items repaired at the facility appear in the forecast.*
2. An Engine Center - External Vendor relationship map. This database depicts the habitual relationships between Engine Centers and external part repair facilities. An Engine Center can often choose between multiple external repair facilities when shipping parts for repair. *The vendor map attempts to identify the percentage of work, by part family, that a specific external vendor typically receives from an Engine Center.* For instance, Cheshire can ship airfoils to Pratt & Whitney Airfoil repair facilities in Dallas or in Connecticut. A vendor map will show the historical percentage of airfoils that each facility typically receives from Cheshire. This data is based on historical ERP transactional data, and refreshed regularly by the demand planning team. A vendor map, created by the demand planning team, captures these relationships to improve the accuracy of the forecast presented to the external vendors.
3. A monthly engine shop visit forecast, delineated by engine model, Engine Center, and workscope, for all engine models that a certain Engine Center repairs. The shop visit forecast is more of an input to the ADPP rather than a data table created by the demand planning team. However, the demand planning team is working closely with the “Fly Forward” initiative to define data requirements and to define the structure of the output from “Fly Forward.” With a detailed engine shop visit forecast delineated by the appropriate criteria, the demand planning team can provide Aftermarket repair facilities with a more

useful part-type demand forecast. For this reason, the synergy between the ADPP and the “Fly Forward” initiative is crucial.

The data tables will be used to filter the global part-type demand forecast, for either internal and/or external demand, and supply the Aftermarket repair facilities with only the information they require, with the detail they require, to optimize operations. These tailored forecasts further reduce variability that an Aftermarket repair facility perceives in the global demand picture, by effectively eliminating the extraneous demand data for a particular facility.

### **7.10 Identifying Potential Sources of Forecast Error For Phase 1**

A key limiting factor in the accuracy that can be achieved in Phase 1 is due the small data sample size. ERP was implemented at the Pratt & Whitney Engine Centers about a year prior to Phase 1 development, and ERP implementation at Pratt part repair facilities will continue through 2005. Therefore, there exists a limited number of complete engine overhaul records in the historical ERP data. For example, during Phase 1 implementation, the number of complete engine overhauls in the Cheshire ERP database ranges from four to twenty-five engines per engine configuration grouping. As the sample size grows, the demand planning team will possess the capability to analyze the data from multiple perspectives, including all the criteria identified in Section 5.3.

However, due to similarities among overhaul procedures and demand patterns, and due to the aggregation strategies employed by the demand planning team, a relatively small sample size can produce a useful basis for demand forecasting. This sample size and forecast accuracy is explored in the next section. With time, this sample size will increase, along with the forecasting capabilities of the ADPP.

There are two other primary sources of potential forecast error that the demand planning team is examining:

1. Part demand forecast errors caused by errors in the engine shop visit forecast.

Since the engine shop visit forecast contains several pieces of information, and

since every forecast is inherently inaccurate to some degree, an error in a single aspect or across several aspects of the shop visit forecast can contribute to the overall error of the ADPP. These errors include:

- Errors in predicting the mix of engine models that will be inducted.
- Errors in predicting the workscopes of engine shop visits.
- Errors in predicting the total number of engine overhauls over a given time period.
- Errors in predicting the Engine Center that will induct a specific engine.

2. Part demand forecast errors caused by errors in the historically-based disposition percentages (engine templates). The ADPP captures historically-based demand patterns and uses these patterns to predict future demand patterns. This forecasting process, like any forecasting process, has inherent forecast error associated with it.

Analyzing the overall forecast error will require the demand planning team to determine the root causes of the error and determine the contribution of each root cause to the cumulative forecast error. Once the root causes are identified, the demand planning team can systematically analyze and adjust the ADPP to account for these sources of error, and produce increasingly accurate demand forecasts over time. The ability to systematically analyze and correct sources of forecast error demonstrates the superior capability of the ADPP over existing forecasting methods used within Pratt & Whitney. This ability is the direct result of the systematic, data-driven process utilized by the ADPP for identifying, analyzing, and predicting Aftermarket demand patterns. Analyzing forecast error is a major focus of the demand planning team for Phase 2 and Phase 3 of the project.

The demand planning team conducted a limited but important effort to determine the level of forecast accuracy that can be achieved in the early stages of Phase 1. This validation process is described in the next section.



### **7.11 The Validation Test of the Engine Templates Using the PW4000, 94-inch Data**

Early in the Phase 1 development, the demand planning team performed a limited test to validate the process of using TEPD profiles to generate credible demand forecasts. The test was limited to heavy overhauls for the PW4000, 94-inch Phase 1 and PW4000, 94-inch Phase 3 engines performed at the Cheshire Engine Center over a three month period. The goal of the test was to benchmark the accuracy that the demand planning team could expect to achieve with the ADPP. Since the ADPP is a new initiative, it was unproven as a valid forecasting model early in its development cycle. The validation test intended to prove that the ADPP concept would work, and would provide reliable and accurate forecasts.

In Phase 1, the demand planning team hoped to achieve a 70% forecast accuracy, meaning that the total forecasted repair and scrap volumes for a given month would be within 70% of the actual repair and scrap volumes. For instance, if the demand planning team forecasted that Cheshire would repair 130 of Part Family "A" in month one, and the actual number of Part Family "A" that was repaired is 100, then the forecast error is  $(130-100)/100$ , or 30%. A 30% error equates to 70% forecast accuracy, which is the initial goal of Phase 1.

It is important to note that for the length of the three-month validation test, the total error was calculated as an absolute error, meaning that errors in successive months did not offset one another. For instance, if the demand planning team forecasted the repair volume for Part Family "A" in month two as 70, and the actual number that was repaired is 100, then the forecast error for the second month is  $\text{abs}[(70-100)/100]$  or 30%. The fact that the error was +30% on the first month and -30% in the second month does not equate to a 0% forecast error overall. Rather, in absolute terms, the forecast error for the two months is calculated by the demand planning team as 30%.

In July 2002, the demand planning team decided to perform a rearward demand forecast to validate the TEPD framework. The approach was to create TEPD profiles for the two PW4000, 94-inch engine configuration groups based on data entered in the Cheshire ERP

database prior to April 1<sup>st</sup>, 2002, and then generate a part-type demand forecast for the following three months.

The TEPD profiles for the PW4000, 94-inch Phase 1 and PW4000, 94-inch Phase 3 were constructed, as described in Chapter 6, based on ERP data mined from Cheshire from August 2001 through March 2002. August 2001 is the date that ERP was implemented at Cheshire, so it represents the beginning of the ERP history at Cheshire.

With the static engine templates and the TEPD profiles completed, based upon data collected in ERP through March 2002 only, the demand planning team generated a part-type demand forecast for Cheshire for April, May, and June 2002. Since the demand planning team knew the exact number of heavy overhauls that Cheshire completed for PW4000, 94-inch engines in these months, the engine shop visit forecast for this test was essentially 100% accurate. Fixing the accuracy of the shop visit forecast was intentional in order to isolate the TEPD profiles as the lone potential source of error between the two initial process inputs. A breakdown of the information available at Cheshire during the validation test is listed below:

PW4000, 94-inch, Phase 1:

Number of historical heavy overhaul records in Cheshire ERP through March 2002: **8**

Number of PW4000, 94-inch Phase 1 heavy overhauls performed in April-June 2002: **4**

PW4000, 94-inch, Phase 3:

Number of historical heavy overhaul records in Cheshire ERP through March 2002: **5**

Number of PW4000, 94-inch Phase 3 heavy overhauls performed in April-June 2002: **3**

The demand planning team generated a part type demand forecast for the two PW4000, 94-inch engine configurations for April through June 2002, using historical ERP data dated prior to March 31<sup>st</sup>, 2002, and compared the forecast to actual Cheshire ERP disposition data for these same months. The demand planning team studied three scenarios in the validation test:

Scenario 1: Use historical ERP data to forecast part demand from the next single engine inducted for each separate Phase 1 and Phase 3 engine configuration.

Scenario 2: Use historical ERP data to forecast part demand from the entire batch of engines inducted in the three month period for each separate Phase 1 and Phase 3 engine configuration.

Scenario 3: Use historical ERP data to forecast the combined part demand forecast for both Phase 1 and Phase 3 engines over the entire three month period.

The results of the validation test are shown below.

### 7.11.1 Validation Results for the Three Scenarios

The validation results depicting forecast accuracy are summarized in the tables below.

Scenario 1:

Phase 1: ERP data from 8 heavy engine overhauls to predict part demand from the 9<sup>th</sup> engine inducted.

Phase 3: ERP data from 5 heavy engine overhauls to predict part demand for the 6<sup>th</sup> engine inducted.

Forecast Accuracy	External Repair ("E")	Internal Repair ("I")	Scrap at Engine Center ("Rb")	Scrap at External Vendor ("Rv")	Serviceable ("S")
Phase 1	63%	69%	75%	93%	71%
Phase 3	55%	49%	80%	96%	54%

Scenario 2:

Phase 1: ERP data from 8 heavy engine overhauls to predict part demand for the next batch of 4 engines inducted.

Phase 3: ERP data from 5 heavy engine overhauls to predict part demand for the next batch of 3 engines inducted.

Forecast Accuracy	External Repair ("E")	Internal Repair ("I")	Scrap at Engine Center ("Rb")	Scrap at External Vendor ("Rv")	Serviceable ("S")
Phase 1	79%	80%	94%	82%	82%
Phase 3	74%	76%	83%	96%	78%

### Scenario 3:

Combine Phase 1 and Phase 3: ERP data from 13 heavy engine overhauls to predict part demand for the next 7 engines inducted.

Forecast Accuracy	External Repair ("E")	Internal Repair ("I")	Scrap at Engine Center ("Rb")	Scrap at External Vendor ("Rv")	Serviceable ("S")
Combined	83%	86%	87%	96%	85%

#### **7.11.2 Analysis of the Validation Results**

While the demand planning team readily admits that the sample size may be too low for rigorous statistical analysis of the results, the team is confident in the results nonetheless. The first result of the test that surprised and encouraged the demand planning team was the level of forecast accuracy achieved from a relatively small data sample size. The analysis for this level of forecast accuracy concluded that since this data was extracted from a single Engine Center, the part inspection criteria and standards for repair versus scrap at Cheshire are very uniform. Therefore, we would expect to find distinct repair and scrap patterns within a relatively small historical ERP data sample size within a single Engine Center.

Also important is the habitual Engine-Center-to-vendor relationships. The external vendors of Cheshire also have uniform standards for dispositioning parts. Since the relationships between Cheshire and its external vendors are relatively constant over the short term, we expect to find distinct external repair and external scrap ratios. Therefore, the historical ERP data is sufficient to predict external repair and scrap ratios with a relatively small sample size of engines.

The second result that is interesting is the increasing level of forecast accuracy as either the historical sample size increases, the number of future inductions increases, or both. Predicting the exact part-type demand profile for a single engine is difficult, because a single engine may be an outlier, and display non-typical demand patterns. In contrast, a

group of engines is more likely to display the typical historical demand patterns exhibited by engines with the same configuration and workscope.

Also, as the data sample size increases, demand trends in the data can be identified more accurately, and used to generate more accurate forecast.

In the opinion of the demand planning team, the results support two primary conclusions:

1. The ADPP is a valid method for generating a part-demand forecast.
2. A large sample size is necessary to achieve consistent accuracy.

Further and more rigorous analysis of forecast accuracy will be the focus of Phase 2 and beyond.

## **8 Chapter 8. The Future of the Aftermarket Demand Planning Process**

This chapter describes the future of the ADPP, including Phase 2 development and implementation, incorporating ADPP into the Sales forecasting process and into the Sales and Operations Planning (S&OP) process, and the future analysis of forecast error.

### **8.1 Phase 2**

At the time this thesis is written, Phase 1 development and implementation of the ADPP is complete. A Phase 1 prototype is currently being tested by a limited group of Aftermarket repair facilities. The demand planning team is soliciting feedback from this limited group of end-users, and will incorporate changes into Phase 2 based on the feedback. So far, the feedback is extremely positive, and Aftermarket repair facilities are providing valuable feedback that will optimize the future capabilities and outputs of the ADPP.

The timeline and the data of final implementation of Phase 2 is dependent upon the completion of supporting initiatives within Pratt & Whitney, including the “Fly Forward” initiative, the Spares forecasting process, and the S&OP process. The demand planning team is actively involved in the three supporting initiatives mentioned above, and will help ensure that the ADPP is incorporated within each initiative. The three initiatives are discussed further in this chapter.

The demand team is moving forward with all aspects of Phase 2 development and implementation. The next several sections will highlight the important aspects of the ADPP that are currently being developed in Phase 2.

#### **8.1.1 Forecasting and Analyzing External Demand**

As stated previously, the demand planning team is working to expand the scope of the ADPP in Phase 2 to forecast external demand. The major challenge involved in this effort involves the limited access to external data. The demand planning team does not have access to the historical overhaul data stored in external Engine Centers. Therefore,

the demand planning team will have to use the Typical Engine Part Disposition (TEPD) profiles generated from internal ERP data as discussed in Chapter 6, based on criteria similar to external demand criteria, and apply them to external demand profiles. The team will modify the internal TEPD profiles using experience and input from Sales representatives that work directly with the external Engine Centers.

The input and market intelligence provided by the Sales and Marketing organization will have a tremendous impact on the effectiveness of Phase 2. With the help of Sales and Marketing, the internally generated TEPD profiles will be augmented to fit the observed demand from external customers, until the demand planning team has a full range of TEPD profiles to account for every external customer and demand scenario.

The scope of the demand that the ADPP will capture or analyze by Phase is listed below.

1. Pratt & Whitney engines in Pratt & Whitney internal Engine Centers (Phase 1)
2. Pratt & Whitney engines in external Engine Centers (Phase 2)
3. Competitor engines in Pratt & Whitney Engine Centers (Phase 2 & 3)
4. Competitor engines in external Engine Centers - for detailed market share analysis. (Phase 3)

### **8.1.2 The “What-if” Analyzer**

The demand planning team is also developing additional capabilities for the ADPP in Phase 2, including the “what-if” analyzer. The concept of the analyzer is to use the ADPP to quickly perform “what-if” analyses, which will generate hypothetical forecasts based upon assumptions about the effects of known or hypothetical future events on Aftermarket demand. Like the ADPP demand forecast, the analyzer will generate tailored results that match the information requirements of the end-user and will be presented in the same format as the ADPP forecast.

Some examples of scenarios that can be analyzed with the “what-if” analyzer include:

- The effect of a war on Aftermarket demand. Or, the analyzer can provide more specific analysis, such as the effect of a war on airfoil repair demand at Cheshire.

- The effect of a large-scale terrorist attack on a commercial airliner as it pertains to Aftermarket demand. More specific analysis will also be possible.
- The effect of widespread bankruptcy in the U.S. Airline industry on Aftermarket demand. The analyzer will also provide specific analysis capabilities, such as the effect of a possible bankruptcy of a major U.S. Airline as it pertains to PW2000 engine inductions by internal Pratt Engine Centers.

The quality of the analyzer will depend on the quality of the assumptions made about the effects of future hypothetical events on Aftermarket demand. The analyzer is currently a concept under development, but it promises to be a powerful analysis tool for management and other end-users.

### **8.1.3 Generating a Detailed Forecast for Spares**

As stated previously in this thesis, the Spares organization would prefer a demand forecast that is delineated by part number instead of by ATA part family. However, due to the chaotic nature of part number configurations among engines, and due to the lack of complete and credible historical part number configurations in internal ERP databases, the ability to generate a demand forecast by part number remains unattainable at this time.

However, the demand planning team is working to provide the Spares organization with a demand forecast that is slightly more detailed than the current forecast based upon ATA part family groupings. The demand planning team, in conjunction with Spares, is developing a probability analysis that will depict the relative frequency with which part numbers appear in the historical ERP transactional data within an ATA part family grouping.

The example of the PW2000, 2<sup>nd</sup> Stage turbine blades introduced in Section 5.1.1 will illustrate the concept of the part number probability analysis. As stated in Section 5.1.1, there are twenty individual part numbers that exist in the Pratt & Whitney inventory that can constitute a full set of sixty-four 2<sup>nd</sup> Stage turbine blades on a PW2000 engine. In the



scenario presented in Section 5.1.1, all twenty part numbers have an equal probability of functioning as a single 2<sup>nd</sup> Stage blade on a PW2000 engine.

However, in reality, certain part numbers represent upgrades of other part numbers, and are introduced to replace obsolete part numbers. The introduction of upgraded versions of part numbers, and other factors such as part number obsolescence, results in the fact that certain part numbers appear on engines much more frequently than others. For the twenty different part numbers that function as a 2<sup>nd</sup> Stage turbine blade, there may be only three or four part numbers that appear regularly in the ERP data for PW2000 engine overhauls. Based on this ERP information, the demand planning team can calculate the historical frequency that each part number appears on certain engines, and apply this historical frequency as a probability forecast for specific parts numbers in the future demand.

Therefore, the demand planning team can provide Spares with a forecast delineated by ATA part family, as well as additional probability information that depicts the frequency that each part number appears in the ERP data for each ATA part family.

#### **8.1.4 Module Level Workscope**

The demand planning team is working with the engine shop visit forecasting teams, such as “Fly Forward” and the Engine Induction Booking System (EIBS) teams, to develop methods to forecast engines by module-level workscope. As stated previously, a “module” is a major section of an engine, such as the turbine module and the compressor module. Currently, the engine shop visit forecast process predicts workscope at the engine level, which does not provide sufficient information about the workscope of the individual engine modules. Compared to the engine level workscope, module level workscope is a more accurate indicator of the number of parts and the workscope of individual parts that are dispositioned from an engine. With module-level workscope information, the demand planning team can significantly increase forecast accuracy for the ADPP.

### **8.1.5 Evolution of the Engine Template**

The demand planning team is expanding the scope of the static engine templates to facilitate the multiple levels of data aggregation requirements of potential end users. The demand planning team is adding data fields for each part number in a static engine template that describes the part number in various levels of abstraction. The information in these additional fields includes component type, stage, engine model, module, and aggregate function.

For example, the PW2000 engine template depicts sixty-four 2<sup>nd</sup> Stage turbine blades, which will also have the following information added (one piece of data per field):

1. “Blade”
2. “Stage 2”
3. “PW2000”
4. “HPT” (High Pressure Turbine module)
5. “Airfoil”

In the existing static engine templates created for Phase 1, a part number is aggregated into ATA part families based upon similarities in the location of a part on an engine and by similarities in repair processes. The additional information will allow end-users to aggregate further, either by product line or by component grouping (also called “commodity grouping”). A commodity grouping provides the ability to aggregate similar parts across different engine models, such as “All 2<sup>nd</sup> Stage Turbine Blades from all engine models” or “All airfoils (blades and stators from both compressor and turbine) from PW4000 and PW2000 engines.” A product grouping provides the same analysis for similar parts with the same product family, as in “All 2<sup>nd</sup> Stage Turbine Blades for PW4000, 94-inch engines” or “All airfoils for PW4000 engines.”

With these hierarchical aggregation abilities, the end-users and the demand planning team will be able to analyze historical demand across many different product lines and commodity groupings, which will greatly increase our understanding of Aftermarket demand and our ability to predict it accurately.

### 8.1.6 Business Warehouse

When the ADPP is complete, the demand planning team intends to store the engine templates and TEPD profiles, as well as all the supporting data tables and data mining algorithms, into **Business Warehouse (BW)**. BW is a data repository that stores data and performs standard calculations and data queries, and makes the results available across the entire Pratt & Whitney organization. The monthly ERP data-mining and data-cleansing process, the creation of TEPD profiles, and the use of supporting data tables can be performed automatically in BW once the ADPP is fully developed. Also, all potential end users can have access to the ADPP data in BW, thus providing Pratt & Whitney with a single, standardized source for monthly Aftermarket demand forecasts.

### 8.2 The Role of the ADPP in the Sales Forecasting Process

The ADPP can automate key steps in the existing Sales forecasting process, and will allow Sales and Marketing to produce accurate operational and financial demand forecasts simultaneously. When complete, the ADPP can provide Sales and Marketing with a reliable annual part-type demand forecast, for both repair operations and replacement parts. As a result, the ADPP will improve the existing Sales forecast in the following areas:

1. The ADPP will provide Sales and Marketing with a standardized process for generating demand forecasts with standardized format and content.
2. The standardized process and format will allow Sales and Marketing to systematically perform trend analysis, and develop market intelligence to determine market share information across different product lines and customers.
3. The time and labor commitments involved in the Sales forecasting process will be significantly reduced by the ADPP. However, an accurate forecast founded on the ADPP will still require manual adjustments and realistic analysis by the Sales and Marketing organization. The benefit that the ADPP provides is an automated process for converting actual, standardized data into an accurate part-type demand

forecast. The ADPP will automate iterative steps in generating a forecast and streamline the existing Sales forecasting process.

### 8.3 The Role of the ADPP in the Sales and Operations Planning Process

At the time this thesis is written, Pratt & Whitney Aftermarket Services (PWAS) is in the process of implementing S&OP. Thomas Wallace, in his book *Sales and Operations Planning: A How-To Handbook*, defines S&OP as:

*[S&OP] is a business process that helps companies keep **supply and demand in balance**. It does this by focusing on **aggregate volumes** - product families and groups - so that mix issues...can be handled more readily. It occurs on a monthly cycle and displays information in both **units and dollars**. S&OP is **cross-functional**, involving General Management, Sales, Operations, Finance, and Product Development...S&OP **links the company's Strategic Plans and Business Plan to its detailed processes**...[and] enables the company's managers to view the business **holistically** and gives them a **window into the future**.<sup>20</sup>*

The ADPP will provide the S&OP with a demand forecast, which can be compared to the capacity of Aftermarket repair facilities and the capacity of the Spares organization. Through the S&OP process, senior management will be able to identify imbalances between forecasted demand and capacity, and work to correct those imbalances proactively.

The S&OP process can also provide the ADPP with the cross-functional input it requires to generate accurate demand forecasts. The concept and the role of the cross-functional team in the ADPP are discussed in Section 7.4. The demand planning team is working closely with the S&OP implementation team to define a process for incorporating cross-functional input from the S&OP process into the ADPP.

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<sup>20</sup> Thomas F. Wallace. *Sales and Operations Planning: The How-To Handbook*. (Cincinnati: T.F. Wallace & Co., 1999); 7.

## 8.4 Future Forecast Accuracy

Determining the accuracy of the ADPP forecast is a major focus of Phase 2 and beyond. The demand planning team is confident that the process will yield sufficiently accurate results, as well as provide a data-based method to analyze historical demand patterns from a variety of perspectives. The sample size of engine overhauls in the internal ERP systems will continue to increase over time, which will allow for much more sophisticated and accurate demand analysis. However, the ADPP forecast accuracy cannot be calculated completely until the supporting inputs from “Fly Forward”, EIBS, and the cross-functional team are implemented and the individual errors associated from these inputs are determined.

### 8.4.1 Continuous Improvement of ADPP

As stated in Section 7.10, two major potential sources of error in the ADPP involve errors in the engine shop visit forecast (“Fly Forward” and EIBS), and errors in the creation or application of the historical TEPD profiles. The challenge of the demand planning team is to develop a process to consistently identify and isolate the root causes of ADPP forecast error, determine their effects on overall process error, and systematically remove or account for the sources of error.

The key benefit of the ADPP over the existing forecasting processes is that the ADPP is a standardized, data-based process that allows for the systematic identification and correction of forecast errors. Errors in the forecast can be identified quickly, whether it be errors in the operational forecast or errors in the sales revenue forecast. Once errors are identified, the ADPP will allow the demand planning team and Sales and Marketing to drill down into the actual data and determine the root cause, as well as the corrective measures necessary to account for errors.

As Thomas Wallace states:

*Even the best forecasts will almost always be inaccurate to one degree or another. The job of a forecaster is twofold. First, they must get the*

*forecast in the ballpark, good enough to enable Operations people to do a proper job of initial procurement and production, capacity planning, etc. The second major goal is continuous improvement in reducing forecast error...[In summary, forecasters should produce] forecasts that are reasoned, realistic, reviewed frequently, and represent total demand.*<sup>21</sup>

The ADPP is intended to provide operational managers with the information they require to optimize their operations. Also, the ADPP is a process that promises to represent total Aftermarket demand and can be continually improved over time.

#### **8.4.2 How Accurate Does the ADPP Have to Be?**

A question that is often asked by Pratt managers is: How accurate does the ADPP have to be to affect the decisions and decision-making process of managers? The demand planning team responds in several ways. First, the demand planning team contends that managers at Pratt today are making operational decisions based on Aftermarket demand forecasts that are much less accurate than the ADPP forecasts, and making decisions based on forecasts that are not founded on actual, comprehensive demand data. A process that creates forecasts from undisputable historical demand data is an inherently better forecasting method than the process currently used at Pratt.

Second, the demand planning team contends that the ADPP forecast explicitly highlights *key historical demand patterns in the actual demand data*, which provides management with a much better “feel” for the Aftermarket business based on undisputable historical data. The trends identified in the historical data can either verify or dispute the perceptions and beliefs held by managers. The ADPP, therefore, is a powerful tool to challenge what Peter Senge calls “mental models” and “leaps of abstraction” that define the way managers view the Aftermarket business.<sup>22</sup> No forecast can be 100% accurate, but perfect accuracy is not necessary for a forecast to be a powerful decision-making tool.

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<sup>21</sup> Thomas F. Wallace. *Sales and Operations Planning: A How-To Handbook*. (Cincinnati, OH: T.F. Wallace & Company, 1999); 28-29.

<sup>22</sup> Peter M. Senge, *The Fifth Discipline*, (New York: Doubleday, 1990); 174-204.

A forecast that identifies the major trends in demand, and a forecast that accurately predicts future trends, is useful to Pratt managers at all levels.

It is important to highlight that the ADPP forecast is one of several inputs into the decision-making process for Pratt managers. The demand planning team believes that it is a powerful input because of its foundation in actual historical demand data. However, like any decision making tool, the ADPP does not eliminate the need for managers to know the business, to understand the data, and to understand the underlying analytical methods employed by the forecasting process.<sup>23</sup>

## **8.5 Strategic Design, Political, and Cultural Issues**

The ultimate success of the ADPP depends upon its acceptance as an integral part of the Pratt & Whitney business process. The demand planning team has invested considerable time, money, and effort toward creating an accurate forecasting process that is highly automated, flexible, and founded on actual demand data. However, the most serious challenges that face the demand planning team as they move forward in the development of the ADPP may not be technical in nature. Instead, the most difficult challenges may be organizational issues that confront the demand planning team and the implementation of the ADPP. These organizational issues, if not properly identified and addressed by the demand planning team and senior management, can threaten the survival of the ADPP, despite its tremendous potential capabilities and benefits. The following sections depict some of these organizational challenges.

### **8.5.1 Strategic Design**

Pratt & Whitney utilizes a hierarchical organizational structure, with distinct roles and responsibilities assigned to specific functional areas. Similar to most hierarchical organizations, communication and coordination across these functional silos has traditionally presented a problem. Peter Senge, in his book *The Fifth Discipline*,

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<sup>2323</sup> Two Crows Corporation, *Introduction to Data-Mining and Knowledge Discovery*, 3<sup>rd</sup> Ed. (Potomac, MD: Two Crows Corporation, 1999); 1.

discusses the communication and coordination problems inherent in many hierarchical organizations:

*...functional divisions grow into fiefdoms, and what was once a convenient division of labor mutates into “stovepipes” that all but cut off contact between functions. The result: analysis of the most important problems in a company, the complex issues that cross functional lines, becomes a perilous or nonexistent exercise.<sup>24</sup>*

Pratt & Whitney continues to address and improve the cross-functional communication and coordination within the organization. Pratt’s commitment to adopting lean practices<sup>25</sup> and its commitment to improving cross-functional communication and coordination has weakened the barriers between the functional silos. Cross-functional initiatives and approaches to problem solving, such as the ADPP, the S&OP process, and the “Fly Forward” initiative, are examples of this continued effort. Key potential benefits from these initiatives are the standardization of business processes and standardization of data across the organization, which will greatly facilitate effective cross-functional coordination and communication.

However, these cross-functional initiatives are still being developed, and as a result they have not been adopted fully into the Pratt & Whitney business process. Until these initiatives are completed, and until the benefits are demonstrated and fully understood, the initiatives remain vulnerable to the forces and norms of the existing hierarchy.

Can a cross-functional process be super-imposed onto a functional organizational structure? When pressure mounts, will members of the cross-functional team advance the interests of their respective functional managers, or will they make decisions based on the collective benefit of the company? The answer to this question lies in the commitment and leadership of Pratt senior management. At the time this thesis is

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<sup>24</sup> Peter M. Senge. *The Fifth Discipline*. (New York: Doubleday, 1990); 24.

<sup>25</sup> James P. Womack and Daniel T. Jones. *Lean Thinking*. (London: Touchtone, 1996); 151-188.



written, there are tangible and positive indications that Pratt's senior management is dedicated to these cross-functional initiatives, and dedicated toward making Pratt & Whitney a continued leader in the industry.

### **8.5.2 Political Issues**

The success of the ADPP is due partly to the ability of the demand planning team to identify key stakeholders, determine their potential level of support or resistance to the project and how this can affect the project, analyze the reasons for this support or resistance, and leverage the stakeholders who support the project while diffusing the resistance.

An example of the success in addressing political issues is illustrated by the relationship between the demand planning team and members of the Sales and Marketing organization. During the initial phases of concept formulation, the Sales and Marketing organization posed the most serious resistance to the implementation of the ADPP. During the initial concept formulation of the ADPP, there existed about ten to fifteen similar initiatives that promised to provide Sales and Marketing with a reliable and automated method for forecasting part-type demand. The demand planning team realized early in the development process that they must differentiate the ADPP from the other demand planning initiatives in order to gain acceptance and credibility from the Sales organization.

To gain the approval and acceptance of Sales and Marketing, the demand planning team invested a significant amount of time and effort in presenting the merits of our project and the potential benefits of the project for the Sales organization. We explicitly and repeatedly stated that our objective was not to replace the existing Sales forecasting process or usurp the forecasting responsibilities of Sales and Marketing. Instead, our objective was to supplement key steps in the existing Sales forecasting process using a highly automated, data-driven process known as the ADPP.

The demand planning team also demonstrated the utility of the ADPP from a Sales and Marketing perspective early in the development process. We developed prototypes of user-interface screens and screens that displayed the content and format of the ADPP output. We stressed that the key differentiator between the ADPP and the other initiatives was the ability of the ADPP to mine and utilize actual demand history (ERP data) in order to generate a part-type demand forecast. Other demand planning initiatives did not utilize actual transactional (consumption) data, nor did they match the accuracy of the ADPP.

It is a credit to the Sales and Marketing organization that they quickly embraced the ADPP once the demand planning team demonstrated the capabilities and potential benefits of the process. Sales and Marketing is now a major supporter of the ADPP, and members of Sales and Marketing are actively involved in Phase 2 development. Their input is crucial in developing the ability to analyze and forecast external demand, and the demand planning team will rely heavily on their market intelligence capabilities to complete the ADPP.

Political issues will continue to confront the ADPP and the demand planning team. As with the previous successes in addressing political dangers, the success in addressing future political dangers depends on the skilled leadership of the demand planning team and other Pratt managers. The leadership of the demand planning team has been instrumental in addressing and overcoming the political issues of the past, and will continue to be instrumental as the process moves forward.

### **8.5.3 Cultural Issues**

John P. Kotter, in his book *Leading Change*, asserts that:

*Regardless of level or location, [corporate] culture is important because it can powerfully influence human behavior, because it can be difficult to*

*change, and because its near invisibility makes it hard to address directly.*<sup>26</sup>

The implementation of the ADPP, as well as other cross-functional initiatives such as the S&OP process and the “Fly Forward” initiative, represent potential challenges to the existing corporate culture of Pratt & Whitney. Examples of these challenges to the traditional culture, norms, and shared beliefs include:

- The concept and process for effective cross-functional communication and cross-functional problem solving.
- The use of standardized data and standardized business processes across the organization.
- Shared responsibilities and decision-making processes among cross-functional managers for key tasks within the organization.
- The concept that Aftermarket demand, although extremely complex, is not as highly variable and uncertain as once perceived, and therefore it can be forecasted with sufficient accuracy.
- An accurate sales revenue forecast alone is not sufficient for optimizing Aftermarket operations.
- An accurate sales revenue forecast and an accurate operational forecast can be achieved simultaneously.

The demand planning team is sensitive to these and other cultural issues. The leaders of the demand planning team have taken the initiative to educate other managers and to explain the concept and the potential benefits of the ADPP to potential end-users. The demand planning team is also working hard to evolve the ADPP and to demonstrate its capabilities to managers at all levels. While no one can predict what the future holds, the ADPP is certainly gaining acceptance and momentum across the entire organization.

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<sup>26</sup> John P. Kotter. *Leading Change*. (Boston: Harvard Business School Press, 1996); 148.





## **APPENDIX 2. LIST OF ACRONYMS**

**ADPP** - Aftermarket Demand Planning Process.

**ATA** - Air Transport Association.

**EBIT** - Earning Before Interest and Taxes.

**EIBS** - Engine Induction Booking System.

### **Engine Modules:**

**LPC** - Low Pressure Compressor

**HPC** - High Pressure Compressor

**HPT** - High Pressure Turbine

**LPT** - Low Pressure Turbine

**ERP** - Enterprise Resource Planning.

### **ERP Part Disposition Codes:**

**E** - External Repair.

**I** - Internal Repair.

**Rb** - Scrap at Engine Center.

**Rv** - Scrap at Part Repair Facility.

**S** - Serviceable.

**OEM** - Original Equipment Manufacturing (or Manufacturer).

**PWAS** - Pratt & Whitney Aftermarket Services.

**S&OP** - Sales and Operations Planning.

**TEPD** - Typical Engine Part Disposition.

**UPE** - Units Per Engine.

**UTC** - United Technologies Corporation.

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