Revenue Management Saves National Car Rental

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In 1993, National Car Rental faced liquidation. General Motors Corporation (National's parent) took a $744 million charge against earnings related to its ownership of National Car Rental Systems. National faced liquidation, with the loss of 7,500 jobs, unless it could show a profit in the short term. National initiated a comprehensive revenue management program whose core is a suite of analytic models developed to manage capacity, pricing, and reservation. As it improved management of these functions, National dramatically increased its revenue. The initial implementation in July 1993 produced immediate results and returned National Car Rental to profitability. In July 1994, National implemented a state-of-the-art revenue management system, improving revenues by $56 million in the first year. In April 1995, General Motors sold National Car Rental Systems for an estimated $1.2 billion.

In the late 1980s, the car rental industry was in turmoil. Low profit margins were subsidized by tax credits. When these tax credits disappeared, the low profit margins were eroded. Automobile manufacturers purchased almost all of the major car rental companies and, in the early 1990s, flooded them with cheap fleet deals. These cars

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came with large manufacturer cash incentives and could be disposed of quickly and easily, as often as every four months, by simply returning them to designated auctions. The car manufacturers placed more emphasis on using their car rental subsidiaries to soak up excess production than to produce profits.

This excess supply in the marketplace led to low pricing. Several major competitors, the price leaders, paid undue attention to market share and made emotion a variable in the pricing equation. Companies still use very low pricing during periods of low demand. These are the rates quoted in Sabre on February 9, 1996 for a weekend rental of a subcompact car at Greensboro, North Carolina for pickup on February 29, 1996:

Alamo	\$14.99
National	\$15.99
Budget	\$16.95
Avis	\$16.99
Hertz	\$16.99

These prices include unlimited mileage. A comparison of these rates with the cost of renting a tuxedo underscores the frequent irrationality of pricing. In the early 1990s, economic conditions and improvements in design and production quality improved demand for American-made cars. The manufacturers dramatically raised the costs of cars to their car rental companies.

These market pressures, combined with the fact that the car rental industry was slow to apply technology, precipitated an industry in crisis. By comparison, the airline industry has successfully demonstrated how to apply the technology of revenue management in a service industry with high equipment and labor costs. Airlines regularly sell cheaper seats to customers willing to accept booking and travel restrictions, such as advance payment, Saturday night stopovers, and penalties for no-shows and cancellations.

The major car rental companies depend largely on corporate customers. They contract at fixed rates with companies who have numbers of employees who travel. Demand peaks for rental cars midweek, forcing all companies to regularly turn down customers. The business customer, who typically travels on these days, pays a fixed corporate rate. This leads to a large excess fleet that is idle on weekends. The car rental industry allows price-sensitive leisure customers to book multiple reservations with no prepayment required. There are rarely penalties for cancellations or no-shows. Customers arriving as much as 12 hours after the specified time of reservation are given the reserved car at the reserved rate. These policies result in no-shows that sometimes exceed 50 percent of reservations. This is a major problem for the industry, which must maintain high utilization to make a profit.

National Car Rental Background

Before National began using revenue management, it struggled with the same challenges as its competitors. But other factors made it critical for National to change quickly. National's business was predominantly composed of corporate customers, who rented cars midweek. National's strategy focused on these business renters and neglected the leisure customers. For several years, starting in 1987, National had no significant advertising campaign. It planned its fleet in one-year cycles, and made very few changes in fleet deployment to meet changing customer demand.

National had three legacy systems to build on: The newly-developed Vehicle Information System (VIS) accurately tracked the fleet, National's Reservation System (RES) was efficient at booking reservations, and the Expressway System (NEX) provided the most rapid rental-and-return process in the industry. By contrast, pricing changes were manual and extremely time consuming. Changes were keyed into National's rates system and then keyed in again to the airlines' computerized reservation systems (CRS). Setting pricing was a shared responsibility. City managers, marketing, regional VPs, senior management, and the pricing group all shared input, with no single person ultimately responsible for a location's pricing. Inventories in the CRS were controlled by field managers with no sophisticated system advising them when to increase or restrict availability. No demand forecasts existed at either the city or the corporate level.

Revenue Management at National Car Rental

In February 1992, several National executives identified two key issues: (1) National was turning down large numbers of customers when cars were available to meet their needs; (2) competitors were raising their leisure prices as the date of rental approached, while National's pricing remained stagnant. National formed the rates automation team (RAT) with a limited mission to determine whether, during periods of high demand, National could raise its prices in the seven booking days before rental. It selected a limited number of cities for a pilot test, for which all processes were manual. It quickly determined that it could raise prices and increase revenues without eroding customer satisfaction. Roll-out of these processes in the organization was met with stiff resistance. "We can't do this; we'll confuse our customers," and "If we do this, we'll confuse ourselves" were typical comments. Deciding that it needed help breaking through these barriers, National asked Aeronomics Incorporated, a revenue management consulting company, to evaluate its unrealized revenue opportunities.

National was at a critical juncture. General Motors had mandated that the company either become immediately profitable, so that it could be sold, or be liquidated. National had already undertaken cost-cutting measures. It had to make more money with the existing operation. Larry Ramaekers, assigned by turnaround specialists Jay Alix and Associates, led the turnaround and acted as president. "We decided to go for a revenue-based turnaround as opposed to a cost-cutting turnaround" said Ramaekers [1995].

Senior management agreed to conduct a needs assessment with Aeronomics Incorporated between January and April 1993. The mission was to understand National's business, quantify revenue potential, recommend organizational structure and staffing requirements, define automation requirements, estimate costs, provide cost/benefit analysis, and prioritize an implementation plan. The assessment identified opportunities for increasing revenue and was presented to senior management in April 1993. National's owner, General Motors, agreed that implementing a revenue management program would be the key impetus to National's turnaround and committed over $10 million to design and build a revenue management system (RMS), acquire the necessary hardware, make changes to legacy systems and bridge them to RMS, and build a dedicated revenue management department. The department would comprise 30 specialists, focusing all of their talents and energies on generating revenue. The application would be phased in beginning July 1993 and would be rolled out to all locations by early 1995. The extremely rapid development of RMS and its immediate implementation to control National's largest demand centers was the single most important factor in keeping National alive.

Revenue management achieves its revenue gains by applying analytic models and methodologies to a planning horizon. By consistently managing capacity, price, and booking requests in a manner that improves revenue per car (RPC), revenue per day (RPD), and utilization levels, a company can make and sustain revenue improvements. There are a couple of basic prerequisites for applying revenue management in a new industry. Perishability is one of the most important prerequisites as Weatherford and Bodily [1992] discuss in their paper on perishable-asset revenue management. The unit of inventory at National is the car rental day, which is lost if it is not utilized. Another prerequisite is a segmentable market. (For a discussion of how revenue management capitalizes on consumers' differential willingness to pay, see Cross [1986].)

The rental car problem exhibits a similar structure to the airline problem, and techniques developed to solve the airline problem have been particularly useful. For example, allocating airline seats at discount prices translates to planning to upgrade a customer's rental car. Overbooking and reservation control are common to any industry that allows advanced bookings. There are important differences. Airlines can target low rates precisely at underutilized capacity. In the car rental situation, the problem is more complex. Rate cuts designed to stimulate demand on low utilization days may increase demand on a day when capacity is constrained and compound the problem. Managing the problem of days when supply is constrained by controlling the length of rentals is a more effective solution, but it requires surgical precision. Conversely, it is reasonably straightforward to increase RPD by increasing rental rates. However, the rental car market is extremely competitive. A price move that makes the company more expensive than its competitors can damage utilization levels. A high RPD is not worth much if most of the fleet is sitting on the lot.

Information Systems

The revenue management system was developed jointly by Aeronomics Incorporated, a revenue management firm; EDS, National's information services provider; and National. It is central to the flow of information at National Car Rental. EDS implemented a comprehensive set of data links with existing information management systems. In particular, the link between RES and RMS is unparalleled in the industry. It is a continuous transaction-level data feed of all advanced booking activity, including availability and booking restrictions. The continuous feed approach provides up-to-the-minute booking levels, forecasts, and system recommendations to revenue managers through the RMS graphical user interface. Transactions include bookings, cancellations, turndowns, and shoppers. Turndowns are booking requests that the company did not accept because of availability controls or booking restrictions. Shoppers are booking inquiries that did not convert to booking requests (Figure 1).

Revenue Management Organization

A major issue during the design phase of RMS was to determine whether a decentralized or centralized solution would have the largest revenue impact, short and long term. A decentralized organization would have been the least painful solution culturally, because city operations managers controlled inventories (that is, reservations system inventories) and leisure pricing. But decentralization would cause a number of difficulties:

—City managers would not make revenue generation the highest priority, because their most immediate problems are customer service and vehicle maintenance.

—Recruiting and training personnel and equipping city offices would be very expensive with a long lead time.

—The revenue manager would be a generalist and would be assigned to "burning problems" not related to revenue generation.

—Pricing practices would not be consistent across locations.

—Managers might be parochial concerning

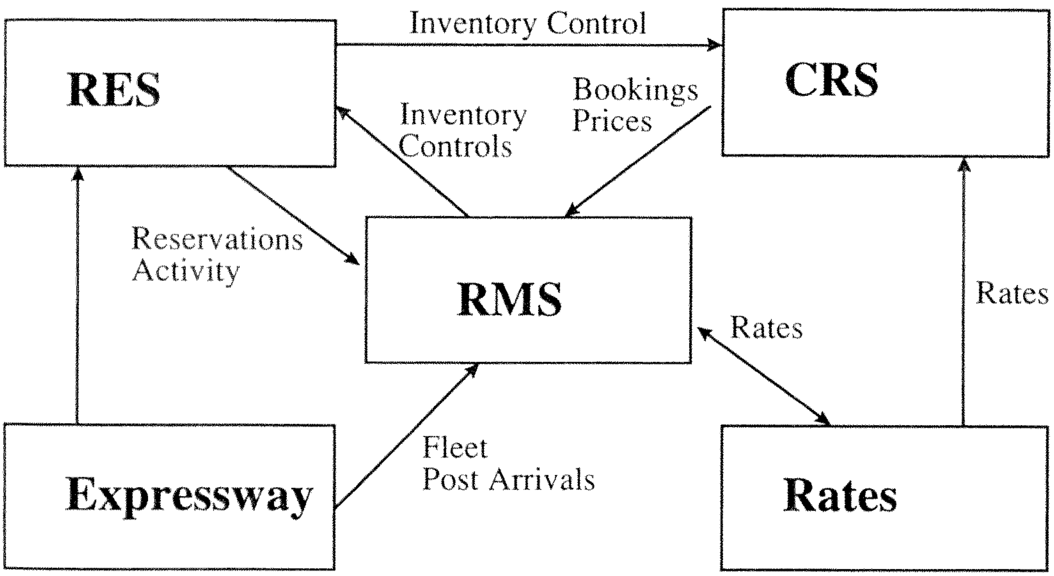


Figure 1: RMS synthesizes information from four principal information systems. Expressway provides current fleet levels to support the capacity-management model and post-arrival data, such as no-shows and walk-ups, for the forecast of day-of-arrival activity. RES provides transaction-level information on booking activity. RMS availability and length-of-rent controls are communicated to RES after review and action by a revenue manager. The Rates system maintains current rate-level information. RMS recommends rate adjustments and provides an interactive rate update interface to the Rates system. Availability and rates are available on a number of airline CRS (central reservation systems). RES updates the CRS whenever availability controls or booking restrictions change. Rates from RMS update CRS rates at regular intervals throughout the day.

fleet disbursement.
—Revenue managers would vary in levels of skills in the field.

The decision to create a centrally located team addressed all of these issues and allowed for the rapid change needed for immediate impact. Corporate revenue managers were given responsibility for pricing and inventory management at the location level. This allowed the revenue management department to share its expertise and information directly with marketing, corporate sales, fleet, strategic analysis, and senior management.

Traditional revenue management organizations in the airline, hotel, and car rental industries have left a dichotomy between the inventory and pricing functions. This is a result of the problem structure. Inventory is usually controlled at the level of a nonstop flight leg, a room night, or a rental day. Pricing is focused at market segments that are often multi-leg, multi-night, or multi-day. However, pricing decisions made independently of fleet availability and customer demand retard revenue generation. The decision to vest National's revenue managers with control of both pricing and inventories represented a big change in culture for National and pioneered new territory for a revenue management organization.

Revenue Management System

The National RMS supports three primary business functions: capacity management, pricing, and reservations control. The capacity management function targets high-valued fleet utilization. Pricing enhances corporate revenues through sensitivity to consumer price tolerance. Reservations control maximizes revenues by accepting or rejecting booking requests based on length-of-rent controls. A sophisticated set of forecasts of demand and consumption patterns supports the analytic model (Figure 2).

RMS functions as both an automated decision management system and an interactive decision support tool. Overnight processes execute the forecasting and analytic models to generate recommendations concerning availability, rate, and length-of-rent control. Revenue managers review thousands of recommendations each day and make, accept, reject, or override decisions based on their knowledge of current market conditions and forecasted demand. Revenue priority indicators assist workflow management by pointing out the greatest revenue opportunity.

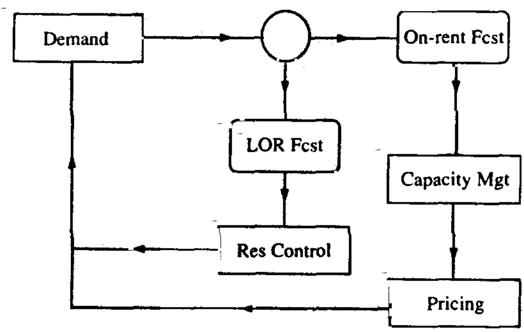


Figure 2: Historic and current demand from the marketplace is used to produce the demand forecasts that support RMS's analytic models. The capacity-management process determines availability levels from the on-rent forecast. Pricing recommendations complement the availability settings. The reservations control process uses more detailed length-of-rent (LOR) forecasts to generate booking restrictions. The combination of availability controls, price adjustments, and booking restrictions changes booking pace. The new booking pace results in new forecasts and system recommendations.

Revenue managers have a wealth of support tools at their fingertips during the review process. The multiple document interface allows them access to reports with historical data and demand and revenue forecasts at all levels of aggregation. They can cut and paste information into spreadsheets, word processors, or electronic fax. One of the more striking features of RMS is the degree of interaction it permits between the revenue manager and the system models. A refresh feature accesses the most recent data on the reservations system and recomputes forecasts based on intraday booking-pace profiles. Recomputed forecasts generate new system recommendations, which the revenue manager can compare to the overnight recommendations as part of the review process. An analyst who disagrees with the forecast can override values. The refresh feature will revise the RMS recommendations according to the user-supplied forecasts.

The logical flow of the models within RMS matches the logical flow of marketing activities within the company. Results from each model depend on the output of logically precedent models. Users can adjust output of any of the models for what-if analysis. All downline models will then produce new recommendations. For example, the analyst can experiment with different rate levels. New length-of-rent controls will reflect the change in the relative valuation of different demand elements. If the analyst wants to try different availability levels, the pricing model will generate new rates. New rates will cause the system to recommend new length-of-rent controls (Figure 3).

Forecasting

A comprehensive set of demand and revenue forecasts supports the analytic models. Demand levels are forecasted at two primary levels of aggregation: length-of-rent and on-rent. Both forecasts represent unconstrained demand, which is the number of cars that can be rented if there are no capacity restrictions. The length-of-rent forecast is a forecast of unconstrained demand for each potential length of rent, for each arrival day in the planning horizon. National intensively manages the booking process at least 60 days in advance of day of pickup. The system generates forecasts for all days within this horizon. It uses demand levels to derive optimal reservations controls. The term *on-rent* refers to the number of cars in use on a specific date. It combines cars that are picked up on that day with cars that are already in use. Capacity management and pricing models rely on the on-rent forecast.

The demand forecasting methodology for all levels of aggregation is based on a combination of long-term and short-term forecasting. The long-term forecast is a time-series model with seasonality factors derived from spectral analysis of historic seasonality. Demand during special events does not distort seasonality. The analyst with the best knowledge of the market defines special events and can override the system-generated factors (Figure 4).

Curry [1993] pioneered the use of Kalman filtering for revenue management. The variable gain approach has several benefits. System initialization uses the same processes as the nightly update. The initial gain is set to unit value and the initialization process adjusts the gain level as it works its way

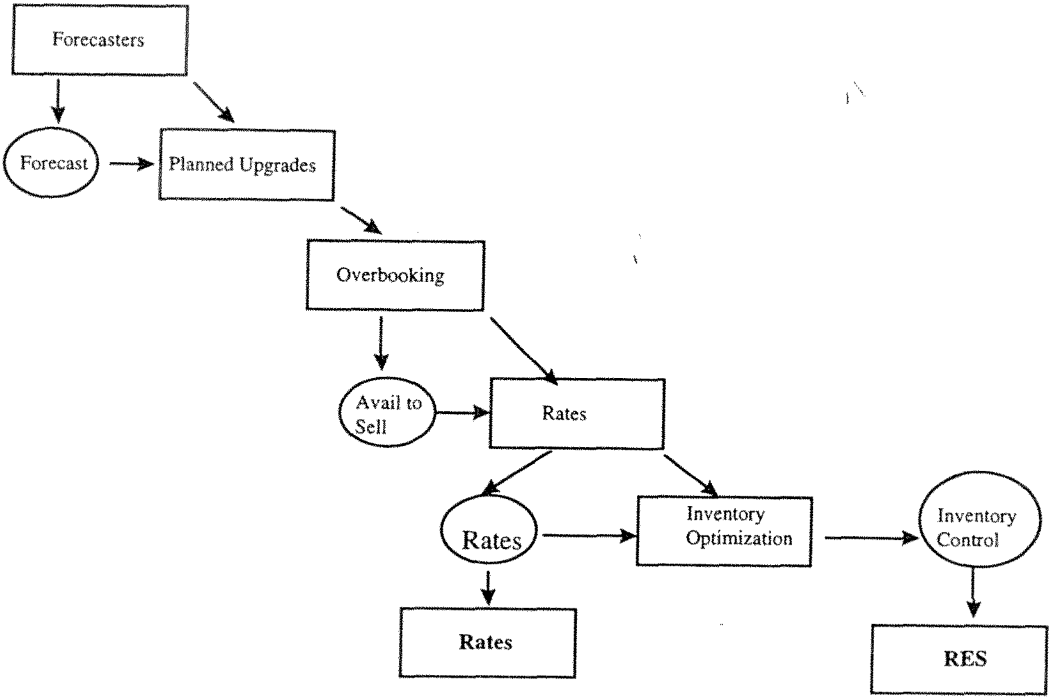


Figure 3: Business processes, analytic models, and revenue manager expertise are tightly integrated in RMS. Each of the ovals represents a point where analysts can adjust system forecasts and recommendations. If the analyst requests a refresh, RMS updates down-line results to reflect the user adjustments. Underlying the decision-making process are expectations of consumer behavior. RMS provides demand forecasts at the on-rent and length-of-rent levels. The analyst can refresh the forecast with real-time booking levels from the reservations system. The capacity management models produce availability recommendations, which can also be adjusted. A refresh at this stage produces new rates and length-of-rent controls. Finally, rate revisions can result in new MLRs (minimum length-of-rent controls). The analyst reviews system recommendations before sending them to the electronic distribution channels.

through the available historical data. Another benefit of the variable gain approach is that the revenue manager can adjust the responsiveness of the forecast temporarily to respond to expected changes in the marketplace. Once the change has taken place, the Kalman filter gains tend toward the steady state smoothing constant.

In generating the short-term forecast, the system considers the offset of the actual reservations level from a booking curve. The booking curve represents the rate at which bookings are expected to accumulate in the reservation system. This offset provides information about the current booking pace, that is, the rate at which bookings are accumulating. The short-term forecast is the expected change in the number of bookings. The final demand forecast is a combination of the long-term and short-term forecasts. The long-term forecast provides stable predictions early in the planning horizon. As more information becomes available from the actual booking

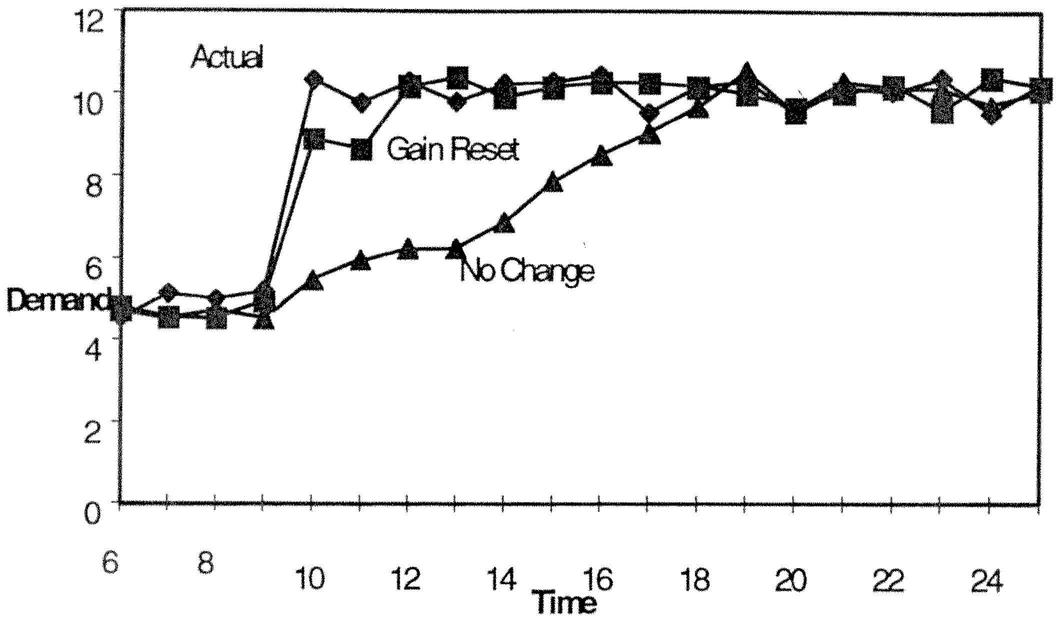


Figure 4: One attractive feature of variable gains is proactive response. The analyst often has advance knowledge that a significant change in the market is about to occur. By proactively increasing the gain, the analyst can ensure that the demand forecast responds to the new demand level quickly.

behavior, the short-term model dominates the forecast of final unconstrained demand.

The system also generates additional forecasts of day-zero activity, such as walk-ups and no-shows. Day-zero is the day a car is picked up by the customer. Day-zero activity includes reservations that do not materialize, that is, no-shows, and requests for cars that do not come through the reservations process, that is, walk-ups. No-shows are a big management problem. The no-show rate is a day-zero effect, but it affects down-line rental days by reducing expected on-rent demand and creating extra availability.

Walk-ups, on the other hand, introduce significant opportunity. A manager can avert an impending oversale situation by turning away walk-up demand. Walk-ups represent a significant revenue opportunity during periods of high demand and low product availability. By predicting walk-up activity, managers can set aside inventory. Walk-ups during these periods represent an opportunity to achieve high revenue per day. Conversely, managers can stimulate walk-ups through aggressive pricing to compensate for underutilization identified late in the booking process. The management of day-zero activity is the responsibility of the field managers. Hand-off of the booking process from corporate revenue managers to field staff on day-zero requires constant communication and information sharing. RMS contributes to this process with distributed electronic reports.

Capacity Management

RMS converts available capacity into revenue. Capacity management is the first step in the process. It includes fleet planning, planned upgrades, and overbooking.

Fleet Planning

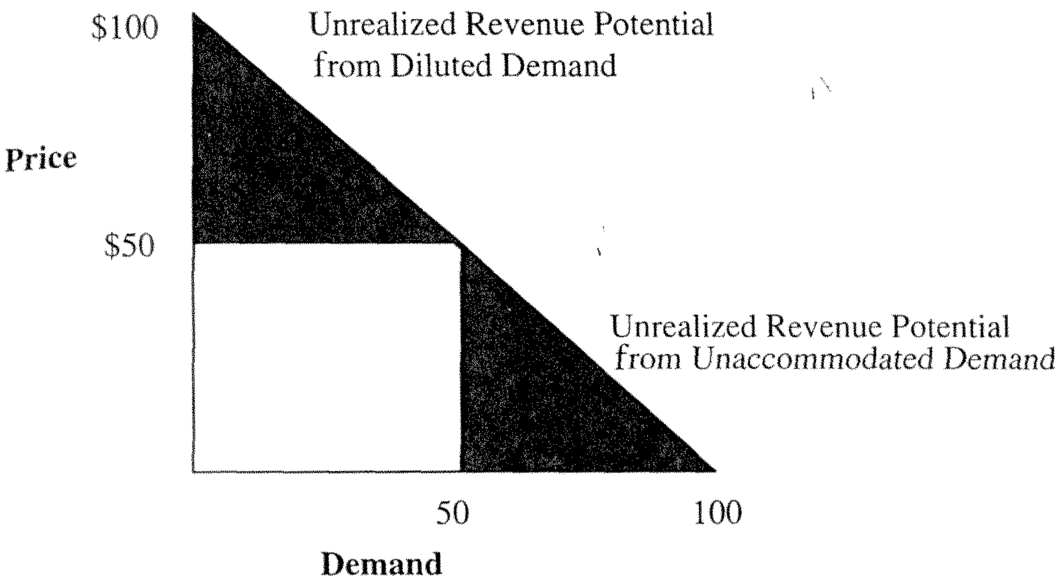
To plan fleet levels, National identifies how much of the available fleet should be at each inventory location to meet expected demand. An inventory location is a geographical area which shares a pooled fleet. It may include several different physical locations. For example, Minneapolis may be an inventory location consisting of two city stations—Minneapolis airport and a hotel station. Capacity is managed at the inventory location level because fleet can easily be moved to meet demand at the various stations. In contrast, pricing is managed at the physical location level as a means of further segmenting the market. National relies on long-term forecasts of demand for each inventory location in its fleet planning. It matches current fleet and expected fleet adjustments to the demand forecasts to determine the placement of cars.

National plans its fleet in three stages: for the short term, it looks at a five-day horizon; for the medium term, it considers 60 days in the future; and for the long term, it looks over the coming 18 months. Short-term planning targets fleet movements between locations, accelerates or retards turnbacks to manufacturers, regulates car-sales activities, and resets one-way pricing to effectively place cars in the proper locations to satisfy demand. In mid-term fleet planning, managers consider the same actions as in the short-term process, but they also redirect new car deliveries, acquire new fleet made available at the last minute by the manufacturer, and move cars by truck or train for longer distances. RMS provides tactical forecasts, notifies the analyst of periods when capacity is dangerously low and automates key components of the tactical fleet-management process.

The involvement of the revenue management department in long-term fleet planning has been instrumental in developing National's annual budget for charge days and revenue per day for each market segment within each city. (A charge day is a rental day that genuinely generates revenue.) This has contributed dramatically to National's success because the RMS forecast focuses on unconstrained demand and has helped break the pre-RMS fleet-planning paradigm. In the past, National would plan its long-term fleets based on historical rental patterns, which restricted growth. With accurate information illustrating unconstrained demand, National was able to increase its fleet in a cost-effective manner to capture a much larger volume of profitable business with resulting increases in revenue and market share.

Planned Upgrades

Revenue management exploits the relationship between segmenting the market and generating revenue. Firms can achieve differential pricing for commodities by instituting fences, such as advanced purchase restrictions, that capitalize on each market segment's willingness to pay. In this way a firm presents a variety of products, all of which are based on a single commodity. The fences discourage revenue dilution because the lower-valued products have restrictions that are unacceptable to the higher-valued market segments. National



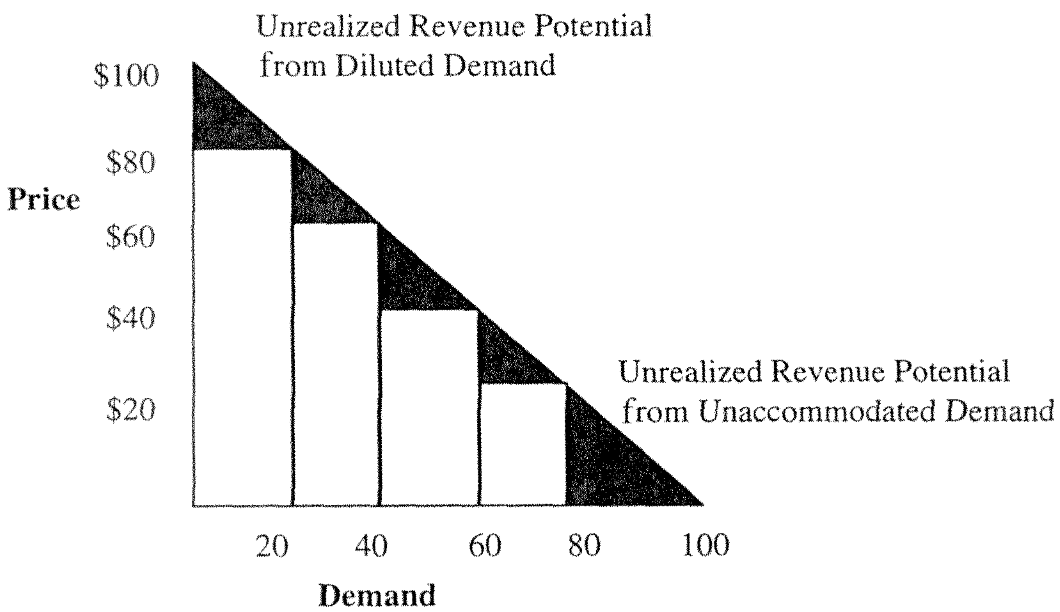


Figure 5: If fences can be found that effectively segment the market, the firm can take advantage of revenue opportunities that arises from differential pricing. It can maximize revenues by setting prices at the willingness-to-pay level of each market segment. The business benefits from the increased revenues, and the consumer benefits because the commodity is available to a broader market. Revenue management has been an important driver in the expansion of National's customer base.

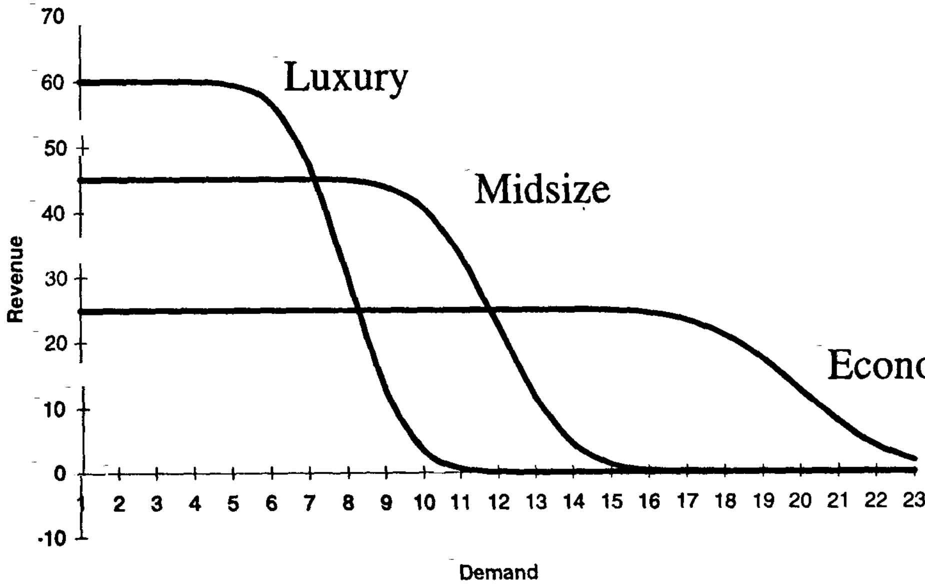


Figure 6: The planned-upgrades model uses a modification of the classical EMSR (expected marginal seat revenue) heuristic that has evolved from Littlewood's [1972] and Belobaba's [1989] research. The cumulative demand distribution is multiplied by average revenue to get expected-marginal-revenue curves for each class. Inventory is protected for each class until its marginal revenue falls below the revenue available from lower classes. Bookings are accepted for a class until they exhaust all inventory not protected for higher classes.

has instituted competitively priced weekly rates, which require the customer to keep the car over Saturday, for price-sensitive leisure customers, fencing out the business traveler who wants to be home on the weekends (Figure 5).

Market segmentation is also inherent in the different car types. The demand for car types falls into definite market segments. Business renters typically demand midsize cars. Low-valued leisure customers prefer economy cars with low rates. More valuable leisure customers want specialty vehicles, such as minivans or four-wheel-drive vehicles. The drawback of accomplishing market segmentation with different products is that a car rental company cannot directly substitute one vehicle type for another. There is a definite upgrade hierarchy that it needs to manage. The planned-upgrades model fits demand into this hierarchy in a way that minimizes revenue dilution while maximizing utilization. It allocates inventory to booking classes based on demand for the booking classes, the number of vehicles that are acceptable to renters in this class, and the expected revenue associated with each class (Figure 6).

In a fully commoditized environment, where all inventory is interchangeable, firms usually adopt a nesting approach. Nesting allows the most valuable booking class access to all available inventory. Subsequent booking classes are allowed access to inventory nominally set aside for the next lower classes. The planned-upgrades hierarchy interferes with a simple nesting approach. It is inappropriate to put higher class customers in economy cars. However, if the company restricts economy bookings to economy cars only, it would miss a large revenue opportunity. Typical fleeting policy is to acquire more large and midsize cars than expected demand requires and fewer economy level cars. The difference in the costs of different sized cars is small enough that the advantages derived from having enough high-valued inventory to meet the high-valued, high-demand periods justify the extra cost. Also, few economy customers complain about getting a better car than they booked for the same rate. The planned-upgrade model decides how many high-valued vehicles to make available to lower booking classes (Table 1).

Fleet in the higher classes that is not required for that class's demand enters the available pool. Classes with more demand than fleet extract fleet from the available pool of higher classes to cover their excess demand requirements. The result is a set of allocations of the number of cars available for rent in each booking class. The actual planned-upgrades model takes account of forecast variability and expected revenues to compute the marginal revenue for each class (appendix). The availability calculation is based on the relative marginal revenues.

Planned-upgrades activity produces a change in availability in the reservations system because customers are driving cars in a class different from that which they booked. When an economy customer arrives at the rental counter and drives away in a midsize car, the availability for midsize demand is decreased for each day the car is on rent. This is because the rental contributes to the current on-rent value for midsize cars even though it is an economy rental. This planned-upgrade effect is particularly pronounced on booking days close to the day of pickup. The model handles the change in availability by revising the on-rent allocation to allow for the number of bookings from other classes it expects to impact the current class.

Overbooking

The airlines have instituted a creative solution to the problem of oversales, which

Class	Fleet	Forecast on Rent Demand	Available Pool	Excess Demand	Available to Sell
Fullsize 4 door	230	165	65		165
Fullsize 2 door	50	60		10	60
Midsize	400	370	30		370
Economy	100	40	60		40
Subcompact	20	165		145	165

Table 1: This table illustrates a simple deterministic case of the planned upgrades process. Available pool represents cars that are available to lower-class bookings. It is computed by a marginal revenue heuristic. Excess Demand represents the fleet requirement for a class with insufficient inventory to meet demand. The revenue manager influences these values through system parameters that provide a throttle to the flow of cars between classes. Available to Sell is the number of bookings National is willing to accept in each car class. The system generates Available to Sell by borrowing cars from the next higher classes so that it satisfies demand.

occur when more passengers show up than can be accommodated. When a flight is overbooked, the airlines in effect hold an auction, offering rewards to any passengers willing to give up their seats and take a later flight. Unfortunately, this is not possible in the car-rental business: customers flow to our counters at different times, expecting and receiving immediate service. They would find it intolerable to be herded into an enclosed area, forced to wait until a certain time, and then to take part in an auction to determine those willing to wait for a vehicle until a later time. Thus, it is critical that our forecast and planning be extremely accurate during peak periods (Figure 7).

The overbooking model revises the results of the capacity management process to account for the impact of no-shows and cancellations. It may be regarded as a mapping from demand space to reservations space where demand space represents actual materialized demand on the day of pickup and reservations space is the number of bookings required, at a given number of days prior to arrival, to achieve that demand level. The overbooking process produces an adjusted, sometimes called overbooked, availability allocation for each car class. The overbooking model identifies optimal overbooking levels by balancing the expected cost of an oversale against the opportunity cost of an unrented car, subject to service-level constraints (appendix). National identifies acceptable oversale risk levels at the corporate level. Individual locations set target utilization levels that adjust available capacity to compensate for the resulting oversale rate and for such operational issues as car turnaround time and

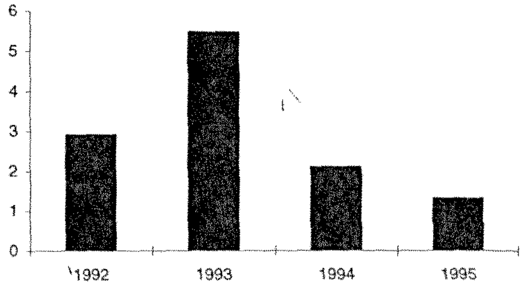


Figure 7: Overbooking compensates for cancellations and no-shows, which are part of the advance booking process. More aggressive overbooking policy results in fewer cars sitting on the lot but increases the instances of "Reservations-No Car." National's record of management of Res/No Car incidents led the industry in 1992. Unfortunately, turndowns were high and utilization was not optimal. In 1993, with GM's direction to turn the company around, utilization improved, revenues improved, but without the tools provided by RMS, Res/No Car incidents rose. When the revenue managers and field managers had the use of RMS (in limited locations) in July 1993, National was not only able to continue to reduce turndowns and improve utilization, but also to reduce service problems. The graph illustrates the great advances made in 1994 and 1995, after the full corporate-wide implementation of the system and department.

discrepancies in checkout/return time of day. (For a discussion of the benefit of overbooking see Smith, Leimkuhler, and Darrow [1992].)

Pricing

The car-rental customer population is made up principally of two segments: corporate and leisure. A corporate customer generally books close to the date of rental, is inflexible in rental and return dates and times, does not shop competitors extensively, is unwilling to prepay, is not willing to stay over a Saturday night, and most important, expects to pay an authorized fixed rate, negotiated and reimbursed by his or her company. The leisure customer, on the other hand, is often willing to stay over a Saturday night, books in advance, is somewhat flexible on time of pickup, for example, willing to wait until noon on Thursdays to qualify for cheaper weekend rates, is willing to prepay rental charges and shops competitors extensively looking for the best value.

The National pricing model links rate levels with availability and consumer booking activity to achieve revenue and utilization objectives. Our initial analysis of National's rate behavior indicated that competitive positioning was the determining factor in its pricing decisions prior to the revenue management program. At times of low demand, sensitivity to competitor behavior is crucial. Utilization levels can suffer drastically from poor rate positioning in the marketplace. During high-demand periods however, the firm can lose large revenue opportunities by following competition-based pricing rules that cause the firm to exhaust inventory by accepting low-valued bookings. RMS implements a demand-based pricing policy. We developed a simple, but extremely effective pricing model to support this policy (appendix).

The pricing model recommends increased or decreased rates based on on-rent demand for a each arrival date. The rates are designed to encourage maximum utilization of rentable capacity. Therefore if remaining demand plus current on-rents exceeds rentable capacity, the model will increase the rate to extract high-valued consumers from the total demand. If remaining demand plus current on-rents is below rentable capacity, it will reduce the rates to stimulate demand. An elasticity model relates historic rate and demand variability. The discrepancy between the demand forecast and the target utilization indicates the required change in booking pace. The elasticity model provides a rate adjustment that will induce this change.

The model relies on the revenue analyst to provide an appropriate base rate for each individual product. The base-rate level embodies the analyst's expertise about such areas as the price tolerance of the market segment and the degree of competition at the location. When the analyst disagrees with a system-generated rate, he or she will either reject it or override it in the process of reviewing the recommendations. When this happens, the pricing model recalibrates around a new base rate. The system infers the new base rate by working backwards from the actual rate the analyst sent to the reservations system and the demand-based rate offset recommended by the elasticity model. The system maintains demand and availability information at a higher level of aggregation than price. RMS-generated price recommendations cause groups of rates to move together. This simplifies rate management by maintaining consistent differentials. The analyst adjusts rate differentials by overriding the current system recommendation. The recomputed base rate will maintain the new

A comparison of these rates with the cost of renting a tuxedo underscores their irrationality.

differential. The pricing model is more than just a price-management system that mimics analyst behavior. By making frequent adjustments in response to market behavior, it extracts the maximum revenue potential from each market segment over the course of the booking process. Gallego and van Ryzin [1994] suggest that one possible reason for revenue management's success is its ability to capitalize on statistical fluctuations.

Traditional revenue management models capitalize on a reduction in customers' price sensitivity later in the booking process, primarily by using restrictions on advance purchases. This kind of market segmentation has been difficult to implement in the car rental industry, but rate premiums for late booking are an alternate means of capturing at least some of this revenue. The pricing model supports rate-premium profiles that offset base-rate levels by different amounts depending on the number of days left before pickup (Figure 8).

The National RMS bases its rate recommendations on forecasts of demand. At times when on-rent demand exceeds availability, the pricing model extracts the most valuable customers from this mix by discouraging lower-valued demand. When competitors undercut National's price at times of high demand, they end up with the low-end customers and leave the higher-valued, later-booking customers for National. RMS allows National to break the "competition paradigm" by recommending when it can price above the competition and when it should price extremely competitively.

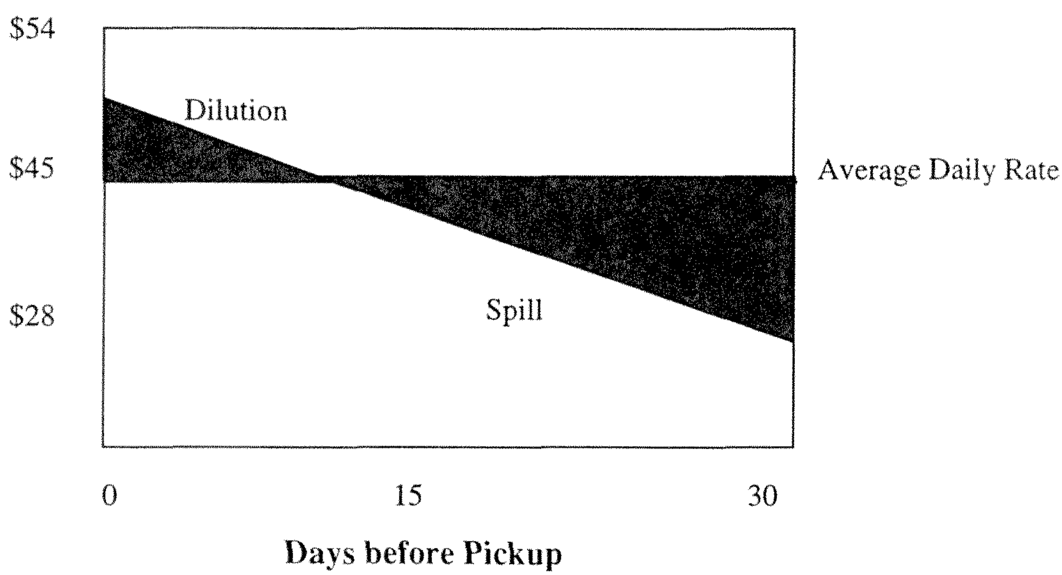


Figure 8: Before RMS, National would set a base price, for example, $45 per day, and it would remain in effect regardless of demand or how far in advance customers would book. Price-sensitive leisure customers would search for a lower rate. The price-insensitive late-booking customer would have been willing to pay more, causing revenues to be diluted.

Reservations Inventory Control

The capacity management and pricing models work closely together to manage on-rent demand. The availability allocations from the planned upgrades model provide a degree of reservations control but do not provide adequate protection for constrained days. The pricing model tries to compensate by adjusting rate levels to achieve utilization targets. Both of these models are limited because they function at an aggregate demand level. By controlling length of rent, National can more precisely trade off between demand elements that are competing for inventory (Figure 9).

Demand forecasts for each length-of-rent category, revenue forecasts based on system rate recommendations, and remaining on-rent capacity provide input for a mathematical programming model that generates minimum length-of-rent restrictions for each arrival day (appendix). The first phase of the model solves a deterministic linear program to identify the length-of-rent categories on each arrival day that provide the greatest revenue. (Williamson [1988] discusses optimization for reservation control.) To implement the LP recommendations, National would need a reservations system with the ability to switch availability on and off for each possible length of rent on each arrival day. The existing reservations controls at National allow specification of minimum length-of-rent controls for each arrival day. Therefore, the second phase of the reservation-control model degrades the full-pattern solution to a set of minimum length-of-rent values and constrained arrival-day indicators. The degradation algorithm reconciles conflicting open/close recommendations within the full-pattern control by weighting each recommendation by the amount of demand it impacts and its proximity to a future constrained day.

For example, the reservation system processes a booking request for a four-day

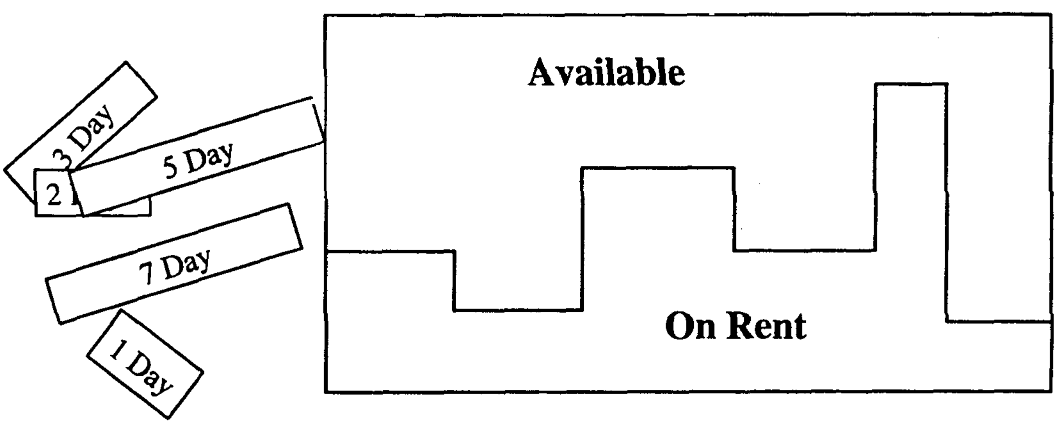


Figure 9: National fits demand for each length-of-rent into remaining capacity using a deterministic linear program. The result is a set of allocation recommendations for each demand element. The linear program's allocations are used to determine minimum length-of-rent (MLRs) controls that can be implemented on the reservations system. The MLRs protect arrival days with constrained capacity while building up utilization on shoulder days (arrival days with availability adjacent to constrained days).

rental arriving on Sunday. It tests availability for all days the booking request requires. Once this test is passed, the length-of-rent specified for the arrival day is considered. The reservation system has a five-day minimum length-of-rent specified for Sunday rentals, but it does not automatically reject the booking. It needs to check if the booking request demands inventory from a constrained day. The reservation system finds that Wednesday is a constrained day so it rejects the booking. Next the reservation system processes a two-day booking request with arrival on Sunday. Because this does not impact Wednesday's inventory, the reservation system accepts the booking. The constrained-day indicator functions as a maximum length-of-rent control. A booking must have a length-of-rent that fits between the arrival date and the next constrained-day indicator, or else have a length-of-rent greater than the specified minimum. In this way, the reservation system protects constrained inventory while building up utilization on the shoulder days (days with inventory either side of a constrained day).

The National RMS sets the standard for revenue management in the car rental industry. It is the first implementation of integrated capacity management, pricing, and length-of-rent control. The length-of-rent optimization, which uses revenue forecasts and detailed length-of-rent forecasts by arrival date, is also unique.

Impact of Revenue Management

When it comes to evaluating revenue management performance, National Car Rental has an advantage over many of its competitors. Traditional revenue opportunity models use demand untruncation strategies to estimate lost demand. There are two principal types of lost demand: *turndowns* are reservations requests that were rejected due to revenue management controls, and *shoppers* are customer inquiries that do not result in reservations requests. Turndowns are key indicators of the effectiveness of capacity management and reservations control. Shoppers provide useful insight into the effectiveness of rate levels. National's reservation system tracks turndowns and shoppers at the transaction level. By combining the reservations that actually occurred with appropriate turndown and shopper transactions, it can compile an accurate reservations history. Analysis of the reservations history with perfect hindsight provides an estimate of the total revenue potential in the marketplace. Conversely, National can estimate the revenue that would be realized in the absence of revenue-management controls. We subtract the revenue from the no-controls scenario from the actual revenue realized to get the

Demand peaks for rental cars midweek.

revenue impact of revenue management at National. National Car Rental also uses this process to evaluate the impact of individual revenue-management controls. For example, it assesses the impact of overbooking by comparing the results of the reservation process with the historic overbooking levels to the results of that process with inventory levels set at the fleet level.

The integration of the revenue management system and the revenue management department have catalyzed change in the organization. It has supported more flexible fleet strategies and tactics. It has led in the development and implementation of new products (Saturday-night keep rates, prepaid rates, guaranteed rates). It has helped National to give customers a higher level of service, especially our late-booking corporate clients. It has upheld our ability to serve customers who suffer broken reservations by our competitors. But most important, in its first year of coast-to-coast deployment, the operational revenue management department allowed the creation and realization of $56 million in incremental revenue.

APPENDIX: Length-of-Rent Control

Reservations are accepted or rejected based on length-of-rent controls. Optimal length-of-rent controls are determined by a revised simplex algorithm with upper bounds for the following formulation:

maximize

$$\sum_{i=1}^{N} \sum_{j=1}^{L} r_{ij} x_{ij},$$

subject to

$$\sum_{k=\max(1,i-L)}^{i} \sum_{j=1}^{L} \delta_{kj} x_{kj} \leq C_i$$

$$\delta_{kj} = \begin{cases} 1 \text{ if } k + j > i \\ 0 \text{ otherwise} \end{cases}$$

$$x_{ij} \leq \mu_{ij},$$

where

N = the number of arrival days in the planning horizon,

L = the number of length-of-rent categories,

$i = \{i: 1, \ldots, N\}$ arrival days within the planning horizon,

$k = \{k: 1, \ldots, N\}$ arrival days that impact day i availability,

$j = \{j: 1, \ldots, L\}$ length-of-rent categories,

x_{ij} = the decision variable for arrival day i and length-of-rent category j,

μ_{ij} = mean remaining demand for length-of-rent category j,

C_i = remaining capacity for arrival day i, and

r_{ij} = expected revenue for length-of-rent category j on arrival day i.

The LP solution is degraded to maximum and minimum length-of-rent recommendations by a voting scheme that weights the LOR recommendations for each arrival day according to its proximity to a future constrained day.

Planned Upgrades

The planned upgrades algorithm is based on a heuristic that was developed for allocating airline reservations inventory on a single flight leg (see Belobaba [1989]). This EMSR (expected marginal seat revenue) heuristic computes protection levels for each booking class. A protection level is the number of cars that should be reserved for the demand in the current class. The optimality conditions for a constrained revenue maximization problem are as follows:

$$\frac{dR}{d\pi_i} = \frac{dR}{d\pi_j} = \lambda \ \forall i \neq j,$$

where

R is the revenue function,

λ represents the expected marginal revenue of the last car allocated to each class, and

π_j is the protection level for class j.

Once the EMSR heuristic determines protection levels for each class, the planned-upgrades algorithm determines the availability in each class. The availability number that appears on the reservations system is the sum of the availability for future bookings and the current bookings for the car class. Availability for car classes with excess demand is computed as the fleet in that class plus any cars available from higher classes to cover the excess demand. The availability for car classes with excess fleet is computed as the fleet less any cars used by lower car classes. Fleet not used by lower car classes is returned to the availability of the original car class. The final avail-to-sell number is the sum of availability, current bookings, and adjustments for planned upgrades that are expected to pick up a car in the next 24 hours.

Pricing

The pricing model recommends rate changes in response to the bookings for each arrival date, relative to the expected booking pace. The magnitude of these recommended changes depends on the responsiveness of demand to rate changes, or the demand elasticity. The basic assumption behind the model is that the historical variance in demand is correlated with the elasticity: the greater the variance, the more responsive demand is to price changes.

The rate changes are limited to a maximum range; for example, between 80 percent and 120 percent of the P_B, base price. The slope of the rate-response function depends on σ, the variance in demand. This relationship can be expressed as an inverse demand function of the following form:

$$P = 1.2P_B - \frac{.4P_B}{2\sigma} Q,$$

where P and Q represent price and demand, respectively, and μ represents the mean demand level. This in turn implies a demand elasticity given by

$$\varepsilon_D = -5 \frac{\sigma}{P_B} \frac{P}{Q},$$

where ε_D represents the own-price elasticity of demand. It is clear that, holding other factors constant, an increase in σ will increase the elasticity of demand and induce smaller price adjustments for a given desired change in demand.

Expected booking pace is maintained at a higher level of aggregation (inventory location) than prices, and there is an operational requirement to maintain constant absolute price relationships across programs and city stations. Therefore the percentage price adjustments returned by this model are converted to absolute dollar changes based on a median rate for the inventory location.

Overbooking

The overbooking model identifies optimal overbooking levels subject to service level constraints. The optimal overbooking level is the point at which the marginal oversale cost is balanced against the marginal increase in revenue due to overbooking.

A = authorization, that is, maximum acceptable on-rent bookings,
C = capacity,
S = number of on-rent cars,
$p(S|A)$ = probability density function of the on-rent demand for a given authorization level,
U = number of empty cars,
O = number of oversales,
OS_Cost = cost of an oversale, and
$Spoilage\_Cost$ = opportunity cost of an empty car.

The expected number of empty cars is given by

$$E(U|A) = \int_0^C (C - S)p(S|A)dS.$$

The expected number of oversales is given by

$$E(O|A) = \int_C^\infty (S - C)p(S|A)dS.$$

The optimum expected revenue for authorization level occurs at the minimum value of

$$Spoilage\ Cost*E(U|A) + OS\_Cost*E(O|A).$$

Since expected oversales increase and expected unused cars decrease with respect to authorization, we can find a global minimum by increasing authorization from capacity until the value of this equation starts increasing. The authorization is constrained above by the following service-level requirement, which is set at the corporate level:

$$1 - \int_0^C p(S \mid A)dS \leq \text{Maximum probability}$$

of one or more oversales.

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