Managing Seasonal Congestion

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Abstract

Seasonality creates demand peaks during predictable seasons, days or hours. We show optimal strategies (pricing and service capacity) depend on the peak type. For example, *Arrival peaks*, where buyers value services more during peaks (Christmas at Disney), compensating for congestion with lower prices only worsens congestion. Best is to increase peak prices and not exploit greater demand with less service. During *Cost* (or *Gasoline) peaks* service providers suffer higher costs (e.g., off-season seafood). Optimal peak prices are either higher with fixed capacity or lower when service can be decreased (lowering costs). *Cross-selling* (or *Popcorn) peaks* allow added revenue from cross selling (e.g., movie concessions at mealtimes). Optimal service capacity increases but not necessarily optimal prices. Finally, C*onsumption peaks* only increase consumption. Optimal prices always decrease, but optimal service capacity does not. We provide logic and intuition for each strategy.

Key words: Seasonality, Pricing, Capacity-Constraints

The Services Marketing Track

1. Introduction

Seasonality dictates business strategy in highly seasonal services such as accounting, advertising, construction, amusement parks, beauty salons, restaurants, car rentals, cinemas, communications, construction materials, education, public utilities, employment agencies, financial services, and lodging (Radas and Shugan 1998, Ni and Sandal 2019).

Our objective is to determine the appropriate strategic response to different types of seasonal peaks – caused by exogenous factors – using queuing theory models of service congestion. We consider pricing and service capacity decisions during peak times (see Rust and Chung (2006), pp. 563-566, for a broad discussion of why these are key variables in service settings). We show that the optimal strategic response depends on the type of peak.

We first introduce as a benchmark a model of how a service provider operates off-peak.

2. Off-Peak

Off-peak, we adopt a well-known queuing model (Naor 1969, Edelson and Hildebrand 1975, Zhao and Zhang 2018, Panwar, Kapur and Singh 2019, Appiah and Osei 2019).

Consider a firm providing a service at price p to customers with valuation v. Strategic consumers, knowing service firms have limited resources, anticipate possible delays. Precisely, customers maximize their expected utility defined as:

$$U_O = \begin{cases} v - \theta p - \kappa E[W] & , \textit{if visiting} \\ 0 & , \textit{otherwise} \end{cases}$$

where θ represents the disutility per unit increase in price, $E[\cdot]$ is the expectation operator, W is a random variable that denotes the wait experienced by a typical customer, and κ is the disutility per unit increase in expected wait. Without loss in generality, set the utility of outside option to zero, and $\theta = 1$, which is equivalent to rescaling.

Similar to Edelson and Hildebrand (1975), we employ a standard M/M/1 queuing system where customers arrive according to a Poisson process, queue, and then receive service distributed exponentially with mean $1/\mu$. The average number of customers served by the system per unit time, if it was constantly busy, is denoted by μ.

We do not assume any specific *service discipline*. For example, we do not require a literal single-file queue or even random customer selection. We only assume an average arrival rate of λ customers per unit time, so that $E[W] = 1/\left(\mu - \lambda\right)$. See Gross and Harris (1998).

Off-peak, atomistic customers arrive until indifferent between visiting the provider and taking the outside option, i.e., $v - p - \kappa/(\mu - \lambda_O) = 0$. At equilibrium, the arrival rate is:

$$\lambda_O = \begin{cases} \mu - \kappa/(v-p) & , \text{ if } p \le v - \kappa/\mu \\ 0 & , \text{ otherwise.} \end{cases}$$

Note, the market fails when the price is so high ($p > v - \kappa/\mu$) that no customers arrive despite zero congestion. So, we assume $\kappa \le \mu(v-p)$ to allow *positive demand.*

The firm's off-peak objective is settling price p and capacity μ to maximize expected profit $\pi_O = p\lambda_O - \mu^2/2$, given a quadratic cost function. The next section considers price-only, capacity-only, and joint optimization.

Like past marketing studies (Chen, Gerstner and Yang 2012), we assume customer arrival decisions depend on expected congestion. We use a M/M/1 because the fundamental insights generated by M/M/1 have proven to be robust (Little 1961), and successfully used in practice.

3. Different Types of Seasonal Peaks

Building on our off-peak model, we now explore several distinct types of observable peaks to provide strategic insights on optimal firm response. That disentangles the different effects for industries that experience more than one type.

Sometimes, institutional constraints constrain some decisions. For example, a cruise ship may have fixed capacity. Reputation effects might keep hospitals from raising prices.

Hence, our analysis takes three perspectives: optimal price at fixed capacity, optimal capacity at a fixed price, and unconstrained price and capacity. Tables 1, 2 and 3 summarize the models and the results. We provide intuition and implications in the next section.

3.1. The arrival (star-bucks) peak

Our first peak allows greater buyer utility during the peak (e.g., coffee in the morning). We call this peak the Arrival or Star-Bucks peak. For this peak, buyer utility becomes $U_A = v + S - p - \kappa/(\mu - \lambda_A)$, where $S > 0$ reflects the added utility from consumption during the peak ($S = 0$ during off-peak). The equilibrium arrival rate is $D_A = \lambda_A = \mu - \kappa/(v + S - p)$ and profits are $\pi_A = pD_A - \mu^2/2$. Table 2 shows the optimal decisions.

3.2. The Cost (Gasoline) Peak

During the cost or Gasoline peak, supplier costs increases during the peak. For example, during seasonal months, wholesale gasoline, seafood, fruits and flower prices increase. During cost peaks, buyer utility $U_C = v - p - \kappa/(\mu - \lambda_C)$ causes peak demand $D_C = \lambda_C = \mu - \kappa/(v-p)$ and peak profits $\pi_C = (p-c)D_C - \mu^2/2$ when c is the increase in marginal cost during the peak. The positive demand assumption yields the optimal decisions in Table 2.

Table 1: Seasonal Peaks

Peak	Utility	Demand Function	Profit
Off-Peak	$U_O = v - p - \frac{\kappa}{\mu - \lambda_O}$	$D_O = \lambda_O = \mu - \frac{\kappa}{v-p}$	$\pi_O = pD_O - \frac{\mu^2}{2}$
Arrival (Star-Bucks) Peak	$U_A = v + S - p - \frac{\kappa}{\mu - \lambda_A}$	$D_A = \lambda_A = \mu - \frac{\kappa}{v+S-p}$	$\pi_A = pD_A - \frac{\mu^2}{2}$
Cost (Gasoline) Peak	$U_C = v - p - \frac{\kappa}{\mu - \lambda_C}$	$D_C = \lambda_C = \mu - \frac{\kappa}{v-p}$	$\pi_C = (p-c)D_C - \frac{\mu^2}{2}$
Cross-selling (Popcorn) Peak	$U_R = v - p - \frac{\kappa}{\mu - \lambda_R}$	$D_R = N\lambda_R = N\left(\mu - \frac{\kappa}{v-p}\right)$	$\pi_R = pD_R - \frac{\mu^2}{2}$
Consumption (Holiday) Peak	$U_H = v\sqrt{N} - pN - \frac{\kappa}{\mu - \lambda_H}$	$D_H = N\lambda_H = N\mu - \frac{\kappa\sqrt{N}}{v - p\sqrt{N}}$	$\pi_H = pD_H - \frac{\mu^2}{2}$
Degradation Peak	$U_h = v\sqrt{N} - pN - \frac{\kappa}{\frac{\mu}{\sqrt{N}} - \lambda_h}$	$D_h = N\lambda_h = \mu\sqrt{N} - \frac{\kappa\sqrt{N}}{v - p\sqrt{N}}$	$\pi_h = pD_h - \frac{\mu^2}{2}$

Table 2: Optimal Strategies

Peak	Optimal Price	Optimal Service Capacity	Equation for Joint Optimization
Off-Peak	$p_O^* = v - \sqrt{\frac{\kappa v}{\mu}}$	$\mu_O^* = p$	$p_O^{**} = v - \sqrt{\frac{\kappa v}{p_O^{**}}}$
Arrival (Star-Bucks) Peak	$p_A^* = v + S - \sqrt{\frac{\kappa(v+S)}{\mu}}$	$\mu_A^* = p$	$p_A^{**} = v + S - \sqrt{\frac{\kappa(v+S)}{p_A^{**}}}$
Cost (Gasoline) Peak	$p_C^* = v - \sqrt{\frac{\kappa(v-c)}{\mu}}$	$\mu_C^* = p - c$	$p_C^{**} = v - \sqrt{\frac{\kappa(v-c)}{p_C^{**} - c}}$
Cross-selling (Popcorn) Peak	$p_R^* = v - \sqrt{\frac{\kappa v}{\mu}}$	$\mu_R^* = pN$	$p_R^{**} = v - \sqrt{\frac{\kappa v}{p_R^{**} N}}$
Consumption (Holiday) Peak	$p_H^* = \frac{v}{\sqrt{N}} - N^{-\frac{3}{4}}\sqrt{\frac{\kappa v}{\mu}}$	$\mu_H^* = pN$	$p_H^{**} = \frac{v}{\sqrt{N}} - N^{-\frac{5}{4}}\sqrt{\frac{\kappa v}{p_H^{**}}}$
Degradation Peak	$p_h^* = \frac{v}{\sqrt{N}} - N^{-\frac{1}{2}}\sqrt{\frac{\kappa v}{\mu}}$	$\mu_h^* = p\sqrt{N}$	$p_h^{**} = \frac{v}{\sqrt{N}} - N^{-\frac{3}{4}}\sqrt{\frac{\kappa v}{p_h^{**}}}$

3.3. The Cross-Selling (Popcorn) Peak

During cross-selling (popcorn) peaks, service providers sell more ancillary services. For example, during mealtimes, movie theaters sell more popcorn and hotels sell more room service. Let N capture cross selling, where $N = 1$ off-peak, e.g., if a movie ticket costs \$6 and a popcorn costs \$3, then $N = 1 + (3/6) = 1.5$ units where popcorn sales are in ticket units. Buyer utility $U_R = v - p - \kappa/(\mu - \lambda_R)$ determines peak arrivals where buyers purchase the main and ancillary services, i.e., $N > 1$; Demand $D_R = N\lambda_R = N[\mu - \kappa/(v-p)]$ and profits $\pi_R = pD_R - \mu^2/2$. Again, see Table 2.

3.4. The Consumption (Holiday) Peak

During Holiday peaks, buyers increase their consumption. For example, during holidays or weekends shopping basket size increases, individuals consume larger quantities of alcohol, and consumers stay longer at restaurants. Unlike the cross-selling peaks, buyers consider additional units when deciding whether to arrive. For example, buyers visiting grocery stores know they will buy more on weekends. Of course, some industries might experience both Arrival (more arrivals) and Consumption peaks (more consumption per arrival). However, again, we wish to sharply contrast the different strategic implications of each type of peak.

Let $U_H = vf(N) - pN - \kappa / (\mu - \lambda_H)$ be the buyer utility function. Let $N = 1$ denote off-peak consumption and $N > 1$ peak consumption. Buyer utility increases with quantity but at a diminishing rate, so that $f'(N) > 0$ and $f''(N) < 0$. We treat N as exogenous (e.g., Hassin 1986) because we focus on exogenous seasonal peaks. However, making N partially endogenous only strengthens our results because an endogenous N is decreasing in price.

To obtain easily interpretable results let, $f(N) = \sqrt{N}$. The strategic buyer utility $U_H = v\sqrt{N} - pN - \kappa / (\mu - \lambda_H)$ considers N and, consequently causes demand $D_H = N\lambda_H = N[\mu - \kappa / (v\sqrt{N} - pN)]$. (The positive demand assumption for the Consumption peak requires $\kappa \le \mu(v\sqrt{N} - pN)$.) Profits during Consumption peak, $\pi_H = pD_H - \mu^2 / 2$, imply optimal price $p_H^* = (v\sqrt{N} - \sqrt{\kappa v \sqrt{N} / \mu}) / N$ and optimal service capacity $\mu_H^* = pN$. The price that optimizes both decision variables satisfies the equation $p_H^{**} = (v\sqrt{N} - \sqrt{\kappa v / (p_H^{**}\sqrt{N})}) / N$, which also gives the jointly optimal service capacity $\mu_H^{**} = p_H^{**} N$. We impose the mild condition that the the *system utilization factor* –some buyers are in the system – is more than one-third, i.e., $\rho = \lambda_H / \mu > 1/3$, then $\partial p_H^* / \partial N < 0$. Then, $\partial \mu_H^* / \partial N > 0$, $\partial p_H^{**} / \partial N < 0$ and $\partial \mu_H^{**} / \partial N > 0$. See table 2 for the optimal decisions.

3.5. The Degradation Peak

Our fifth peak considers service providers that face peak degradation in service capacity despite no additional arrivals. For example, leisure travel bookings are more complex that business bookings. Suppose the peak has more complex orders per buyer which increases wait times but less than an increase in total buyers. Buyers, deciding whether to arrive, anticipate degradation to $\mu / g(N)$ where $g(1) = 1$ and $g'(N) > 0$ when buyers purchase N units. Consider the case when degradation occurs proportional to increased utility, i.e., $g(N) = \sqrt{N}$.

Buyer utility $U_h = v\sqrt{N} - pN - \kappa / [(\mu / \sqrt{N}) - \lambda_h]$ causes peak demand $D_h = N\lambda_h = \mu\sqrt{N} - \kappa\sqrt{N} / (v - p\sqrt{N})$ and profits $\pi_h = pD_h - \mu^2 / 2$ where $\kappa \le \mu(v - p\sqrt{N})$.)

Maximizing profits yields the optimal Consumption peak price. See table 2.

Table 3: Findings: Optimal Decisions Compared with Off-Peak

Peak	Optimal Price	Optimal Service Capacity	Jointly Optimal Price	Jointly Optimal Service Capacity
Arrival (Star-Bucks) Peak	Increases	No change	Increases	Increases
Cost (Gasoline) Peak	Increases	Decreases	Decreases	Decreases
Cross-selling (Popcorn) Peak	No Change	Increases	Increases	Increases
Consumption (Holiday) Peak (ρ>1/3)	Decreases	Increases	Decreases	Increases
Degradation Peak	Decreases	Increases but less than without degradation	Decreases	No Change

4. Findings and Implications

Table 3 reveals that different strategies are often appropriate for different seasonal peaks (defined from observable factors). For example, price should increase for Arrival peaks, decrease for Consumption peaks and not change for Cross-selling peaks when service capacity is held constant. The mathematics is critical; without rigorous proofs, slightly flawed intuition could easily justify incorrect strategic response to the peak.

First, we must understand why peaks occur. Although service providers could create endogenous peaks by decreasing prices, many providers face exogenous peaks, outside their control often created by seasonality. The Arrival (Star-Bucks) peak, exhibits increased buyer utility for the service, which causes buyers to tolerate greater congestion during the peak, thus more buyers arrive. Depending on buyer aversion to congestion (κ), buyers are partially deterred from arriving. However, attempting to compensate these buyers with lower peak prices only exacerbates the problem, because lowering peak prices only encourages still more arrivals. Best is to raise prices to deter some arrivals while obtaining higher per unit profit margins. Stronger peaks (larger S) require larger price increases because the price elasticity decreases more. In contrast, it is optimal to maintain the same service capacity regardless of the strength of the peak when price is held constant. The reason is that changes in capacity have the same incremental impact on demand during the peak and off-peak periods. Increasing capacity would attract the same number of new arrivals. Moreover, the cost of capacity remains constant. Hence, the same capacity decision is optimal both peak and off-peak. However, simultaneous optimization of both price and capacity produces higher optimal capacity, because increases in the optimal peak price also increase per unit profit margins. The latter increase creates an incentive to attract additional customers. Consequently, peak capacity levels increase as larger profit margins justify it.

In sum, Arrival peaks reproduce conventional economic wisdom on price, i.e., when demand increases, raise prices because less effort is required to attract buyers. Congestion only amplifies this result because, beyond improving per unit profit margins, higher prices lessen congestion. However, capacity decisions differ from conventional wisdom, because lower capacity levels cause buyers to depart more slowly, which causes increased congestion.

The Cost (Gasoline) peak requires a different strategy depending on whether the service provider can change the peak capacity. If the provider cannot, then it is optimal to increase price, passing on some increased costs to buyers. However, if the provider can optimize capacity, then it should respond to higher costs with lower capacity. Less capacity causes fewer arrivals. Perhaps, airlines facing higher fuel costs should cut both the number of flights and the fare for those flights to both lower costs while achieving higher capacity utilization.

The Cross-selling (Popcorn) peaks are extraordinarily interesting because there is no price change when peak capacity remains unchanged. The reason is that cross-selling (or up-selling) occurs after buyers arrive and so Cross-selling peaks have no direct impact on arrival rates. Buyers are more profitable with cross-selling, so we might incorrectly conclude that price decreases to attract more buyers are best, but price decreases also lower unit profit margins. Instead, service providers should attract more buyers by increasing capacity and decreasing expected congestion. Cross-selling during the peak justifies the additional capacity cost. Conventional wisdom returns when both capacity and price can change, then higher capacity causes more arrivals allowing price increases, resulting in higher profit margins.

Unlike the Cross-selling peak, our Consumption (Holiday) peak involves buyers who foresee greater consumption and corresponding congestion when deciding whether to arrive. This peak produces still another optimal strategic response that often involves price decreases. The precise strategic response depends on the system utilization factor ($\rho = \lambda_H / \mu$) when service capacity remains constant. We use ρ because we can observe ρ, but this condition is also a condition on N. Precisely, $\rho > 1/3$ is equivalent to $N > (9\kappa / (4\nu\mu))^2$. When N is large, i.e., $\rho > 1/3$, then the optimal strategic response is to lower price, not to compensate for increased congestion, but instead to attract new buyers who have become more profitable because they buy multiple units. Lower prices have a greater impact on arrivals (than with previous peaks) because arrival decisions are based on Np rather than p. For that reason, buyers tolerate additional congestion given a greater sensitivity to price reductions. However, when N is small, then the impact of price reductions is smaller, i.e., Np is closer to p. Thus, when N is small, greater congestion from slightly more arrivals makes more arrivals less valuable, and best is to raise margins to decrease congestion and increase profit margins. The Cross-selling peak mimics an Arrival peak in this case. When N is large, however, the increased quantity for each arrival overwhelms the impact of congestion, and best is to lower price to encourage more arrivals by these more valuable buyers.

In contrast, optimal Consumption peak capacity levels always increase for several reasons. First, higher capacity attracts more buyers who buy larger quantities. Second, better service causes buyers to consume more quickly, depart sooner, and lessen congestion. Finally, unlike lower prices, higher capacity keeps maintains per unit incremental profit margins.

Holding price constant, although increasing capacity is optimal, buyers may still complain that capacity is insufficient during seasonal peaks, because buyers do not understand that the higher capacity will be insufficient to overcome the greater congestion from additional arrivals. Precisely, optimal peak capacity increases ($\mu_H^* > \mu_O^*$), but its positive effect on service is more than offset by increased congestion, i.e., $\kappa / (\mu_H^* - \lambda_H) > \kappa / (\mu_O^* - \lambda_O)$.

In sum, both optimal pricing and service capacity strategies for Consumption peaks sharply diverge from conventional wisdom for traditional demand peaks because one person buying two units is no longer equivalent to two people each buying one unit. In queuing, one person buying two units causes less congestion than two people each buying one unit. When buyers are congestion averse, firms prefer fewer buyers who purchase larger quantities. Thus, with Consumption peaks, service providers should decrease peak prices while raising service capacity. With increased congestion during Arrival peaks, optimal prices increase to lessen congestion, not decrease to compensate for it. With less congested Consumption peaks, best is to decrease prices to encourage arrivals by more profitable buyers, who purchase larger quantities, because buyers make arrival decisions based on expected congestion.

When we allow for service degradation, we obtain another interesting finding. Although optimal service capacity increases without degradation, there is a smaller increase or no increase when there is no degradation. This result seems counter-intuitive because one would ordinarily expect that enhancing service is more important when service degradation occurs. The correct intuition is that when degradation occurs, any improvement in service also suffers the same degradation. Service capacity increases are partially thwarted by degradation, making them less profitable. Hence, the return to additional service is lower with degradation.

It is interesting that, unlike traditional queuing systems without strategic users, increasing service capacity during Consumption peaks raises capacity utilization ($\rho = \lambda / \mu$). Hence, although buyers are served more quickly, the increase in service rate is more than offset by increased arrivals attracted by better service. This is a general feature of all of our peaks.

In sum, the optimal strategic response is very sensitive to the type of peak.

5. Conclusions

Seasonality impacts virtually every organization. We analyzed the optimal strategy for different types of seasonal peaks, defining each peak with a precise, qualitatively observable cause (e.g., greater buyer utility, higher consumption rates). Three general findings emerge:

- First, the appropriate response to seasonal peaks is highly dependent on the peak type. Peaks vary on the number of buyers, quantity purchased, whether costs change, whether service capacity degrades, and what buyers consider when making arrival decisions.
- Second, marketing strategies can cause unexpected outcomes when strategic buyers consider expected congestion, e.g., improving service rates *can* increase congestion.
- Third, although virtually all conventional economic and marketing demand models assume two buyers purchasing one unit each is equivalent to one buyer purchasing two units (because both events result in sales of two units), these cases are not equivalent when more buyers cause higher congestion.

We also provide many specific findings related to managing seasonal congestion.

- When buyers get greater utility during the peak (Arrival peaks), we get more arrivals, more congestion, higher optimal prices, and either higher or the same optimal level of service. Higher prices discourage arrivals, in contrast to, compensation for congestion.
- When costs increase during seasonal peaks, we get Cost (Gasoline) peaks which cause fewer arrivals (after price increases), less congestion and lower optimal capacity. Optimal peak prices depend on whether the service provider can adjust peak capacity. Without that ability, the optimal price increases. With that ability, it is best to decrease optimal prices. The reason is that lower capacity decreases the number of arrivals and makes it profitable to attract more arrivals with a lower price. When capacity remains constant, best is to pass on some costs to buyers through higher prices.
- When buyers purchase greater quantities during the peak (Popcorn peaks), we get the same or higher optimal price relative to off-peak. When capacity remains unchanged, the peak price remains unchanged because buyer price sensitivity fails to change. When we can change peak capacity, best is to increase it to attract more buyers who now purchase more units during the peak. The service provider should also increase price to lessen the congestion created by higher service capacity while increasing profit margins.
- In Consumption (Holiday) peaks, buyers make arrival decisions expecting to consume

greater quantities. A Lower peak price is optimal. Although it attracts more buyers, there is less congestion per unit purchased because each buyer purchases more.

- When greater consumption during Consumption peaks cause service degradation, service providers should not increase capacity, or do so to a lesser extent than when degradation is absent. The reason is that degradation decreases the marginal return on additional service. With degradation, buyers enjoy a fraction of any service improvement, decreasing the return on higher service capacity.
- Although service providers might increase service capacity during peaks, buyers will still complain about worse service. This paradox is resolved by understanding that although peak capacity is higher, additional arrivals more than offset it.
- Finally, we note that when we can inventory strategic buyers (in the system), we lose the traditional concept of service capacity. Trying to lower prices for better capacity utilization loses strategic buyers who anticipate more congestion.

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