SUTD CARPARK

~Revenue Management~

2016 Term 5 ESD 2D Project: Operations Management & Statistics

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EXECUTIVE SUMMARY

The main subject of this project is SUTD's basement carpark, which has a capacity of 288 car parking lots, of which 151 are reserved as season lots and the remainder serve as visitor lots. A preliminary background study has found that members of SUTD are generally unhappy with the current monthly season parking prices, and that due to the carpark's proximity to Singapore Expo, the visitor lots may be completely occupied, while empty season lots remain, resulting in potential revenue loss.

The team had conducted a survey which found a statistically significant difference in demand for season parking when prices for the monthly season parking are changed. Using the survey data, the team modelled a linear relationship between season lots and price, thus facilitating predictions in how demand for season parking changes based on price. An analysis of the count of daily vehicle entries into SUTD was also done in conjunction with a time-study analysis of the carpark to determine the distribution in demand for visitor lots.

With the above information, the team applied models of revenue management, specifically that of booking limits, to determine the optimal number of lots that should be set aside as season lots, based on a range of prices for monthly season parking. Subsequent analysis evaluated the effect of adding a key restriction in the season parking lots such that only members of SUTD could purchase season parking passes.

The analysis showed that while the current combination of monthly season parking prices and number of season lots that the university has set generates a relatively high daily revenue, there is scope for further improvement, such that more revenue could potentially be generated even with a lower monthly season parking price. As such, the team would like the university to strongly consider implementing a revised pricing scheme for season parking, as well as adjusting the number of season lots appropriately in the near future, so as to be able to generate more revenue from the carpark.

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1. INTRODUCTION

SUTD, Singapore's fourth public university, specializes primarily in the fields of Architecture and Engineering. In SUTD, there are approximately over a thousand students, faculty members and staff, many of whom commute to SUTD by driving. As such, SUTD provides a number of carparks, the largest of which is the basement carpark located at the basements of Buildings 1, 2 and 3. This carpark, which shall be the focus of this project, houses a total of 288 carpark lots, comprising of 151 lots reserved for season parking (season lots) and 137 lots that are open for the general public (visitor lots). Season pass holders currently pay $90 a month to park in the red lots, while visitor lots pay a rate of $1.60 per hour or part thereof.

Since the implementation of carpark fees in late August 2015, school members have not been very receptive of the carpark rates, with some even claiming the rates to be unjust. Separately, with SUTD's close proximity to Singapore Expo and Changi Business Park, there have been instances of all available visitor lots being fully occupied, while there were empty season lots, representing a potential loss of revenue. As no formal study had been conducted regarding the carpark pricing in SUTD, this project therefore aims to utilize the tools of statistics and revenue management to study the current carpark pricing, and suggest suitable changes to both the prices of season parking and number of lots to set aside as season lots, so as to maximize the revenue generated by the carpark.

2. DATA AND METHODS

2.1. Data Sets

Data Set	Data	Acquisition Type
D-01	Count of daily vehicle entrances into SUTD (Aug 2015 - Feb 2016)	Given

D-02	Survey on SUTD school members	Manually Recorded
D-03	Time-studies of SUTD Carpark April 2016	Manually Recorded

Table 1: List of Data Sets used

2.2. Statistical Analysis

2.2.1. Demand for season lots: ANOVA, Bonferroni, Regression

Survey data (D-02) was used to determine the relationship between price and demand for season lots. The survey asked respondents of their willingness to purchase season parking passes at various price points[1] on a scale from 1 to 5.

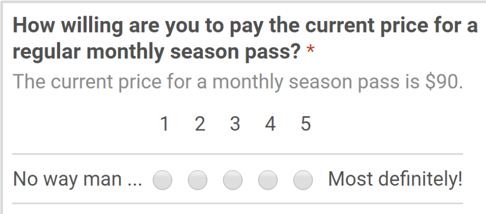


Figure 1: Sample survey question

A Single-Factor Analysis of Variance (ANOVA) was performed on the willingness scores to determine if there was any statistically significant differences in mean willingness scores between any of the price points. The results are shown below:

Group	Undergraduate	Faculty & Staff
Results	F-Statistic = 27.14 $F_{0.99, 2, 126} = 4.78$	F-Statistic = 40.34 $F_{0.99, 2, 225} = 4.70$
Analysis	Reject null hypothesis → At least one price point affects willingness scores	

Table 2: Results of ANOVA Single-Factor Experiment of prices on willingness scores

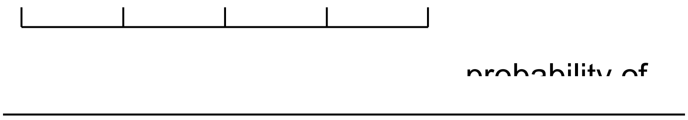
Following this, the price points were tested pairwise to determine which price points have significantly different mean willingness scores. The Bonferroni method was used to counter the problem of multiple testing. In the Bonferroni method, the null hypothesis is rejected when the absolute difference in mean willingness scores is greater than the critical value. All pairs of price points have significant differences in mean willingness scores at the 99% confidence level, as shown in the table below.

[1] The price points are $55, $65, and $85 for undergraduates, and $80, $90, and $110, for faculty / staff.

Group	Undergraduate			Faculty & Staff		
Price point pair	\$65 vs. \$85	\$55 vs. \$65	\$55 vs. \$85	\$90 vs. \$110	\$80 vs. \$90	\$80 vs. \$110
Absolute Difference in mean	0.93	0.72	1.65	1.01	0.82	1.83
Critical Value (99%)	0.67	0.67	0.67	0.60	0.60	0.60
Analysis	All price points have statistically significant differences in the mean willingness scores					

Table 3: Results of Pairwise Comparisons using the Bonferroni Method

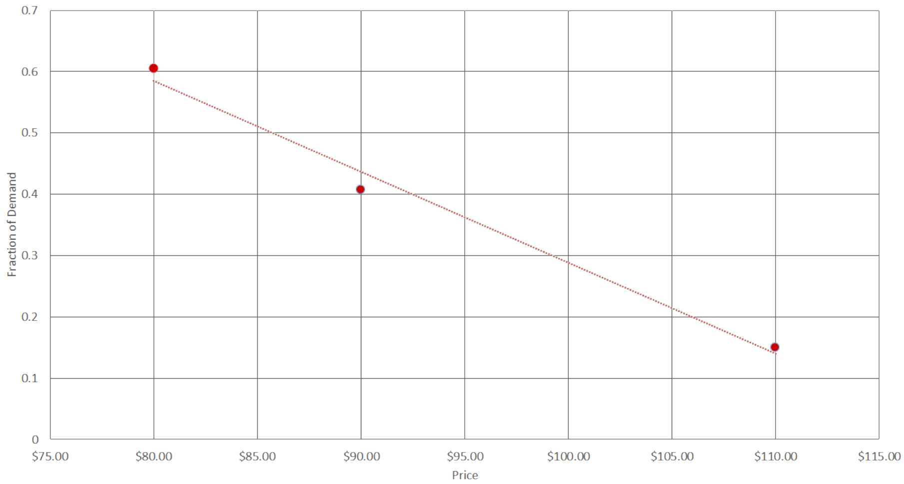
The demand for season passes was inferred from the willingness scores using the following method:



The overall demand for each price point is expressed as a proportion of the total population. This was calculated by taking the weighted average of the probabilities of taking up season passes, where the respective weights are the number of people who responded with a particular willingness score. This is given by the equation:

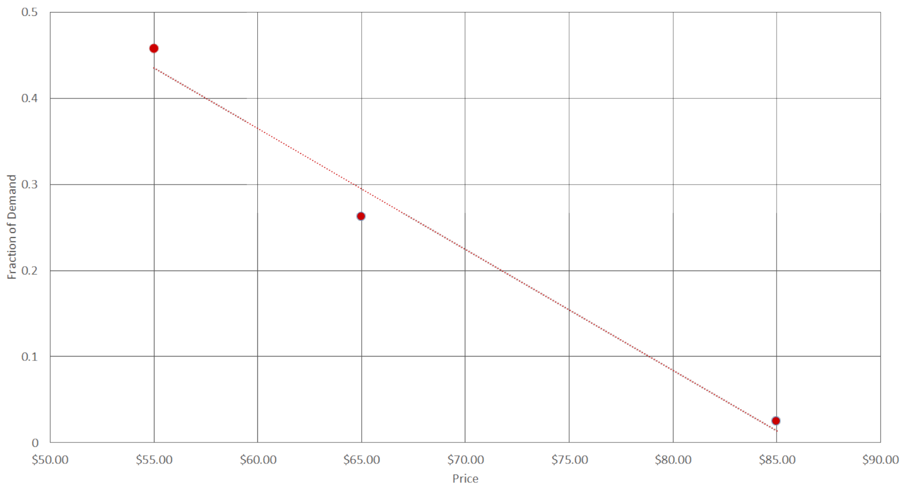
$$D = \sum_{w=1}^{5} p_w n_w$$

where D is the overall demand at a particular price point and p_w is the probability associated to willingness score w. The overall demand was then plotted against its associated price point and a regression line was obtained, modelling the assumption that demand is a linear function of price. As such, by extrapolating the regression line, the price at which demand for season lots would be 100% was estimated to be \$52.04 for faculty / staff and \$14.86 for undergraduates. These values would be used in the subsequent revenue management segment.



Slope: -0.0148 Intercept: 1.772 Price at which demand becomes 100%: $52.04

Figure 2: Regression line of Price vs. Demand (Faculty / Staff)



Slope: -0.0141 Intercept: 1.209 Price at which demand becomes 100%: $14.86

Figure 3: Regression line of Price vs. Demand (Undergraduate)

2.2.2. Demand for visitor lots: Q-Q Plot, Chi-Square Goodness of Fit

The demand distribution for visitor lots was required for the analysis under revenue management. However, due to privacy concerns, parking data at the individual car level (such as type of parking, type of car, duration of parking) was not made available. As such, a combination of methods was used to estimate the number of visitor lots occupied for each weekday. For the mean, a series of time studies (D-03) was done to determine the average number of cars parked at the visitor lots; this figure was used as an estimate of the demand for visitor lots. As for the variance, in order to improve the accuracy of the estimation, the daily number of entries into the carpark was used (D-01), for which there were over 190 days of data available. The following equation was used as a guide in estimating the demand for visitor lots:

*Total # of entries = (# season ticket holders * K) + # Delivery vehicles/Drop-offs + # high-paying drivers*

With the assumption that the number of season ticket holders and number of delivery vehicles is constant, the variance in high-paying customers (who occupy the visitor lots) can then be determined. The following table lists the key parameters listed above and their estimated values.

Number of season ticket holders	90
K (Constant that captures how many times that season ticket holders may drive into the carpark daily)	1.5
Mean of number of high-paying drivers	200
Standard deviation of number of high-paying drivers	98

Table 4: Key parameters needed to estimate demand for visitor lots

In order to facilitate the analysis under revenue management, the distribution of the demand for visitor lots needs to be known. As a preliminary analysis, a Q-Q plot of the number of occupied visitor lots against a standard normal distribution was made, producing the following figure:

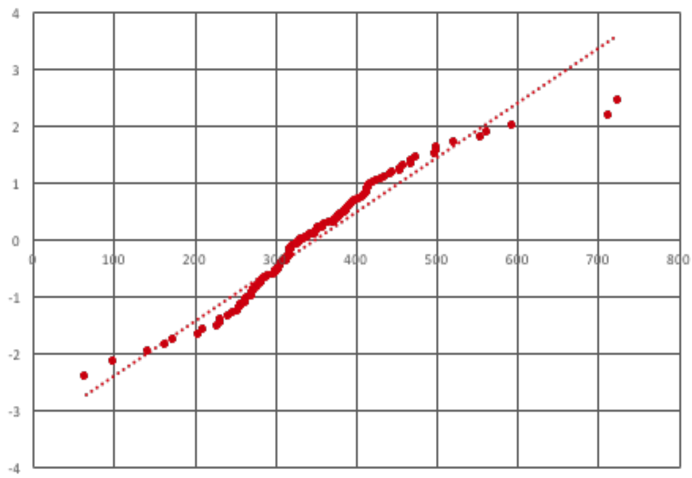


Figure 4: Q-Q Plot of the number of high-paying drivers vs. Standard Normal Distribution

As the Q-Q plot looks approximately linear, a goodness-of-fit test was also carried out against a Normal distribution with mean 200 and standard deviation 98. The calculations are summarized in the next table:

Demand	Observed	Expected
0 - 50	5	8.06
50 - 100	7	11.63
100 - 140	20	14.9
140 - 180	29	19.07

180 - 220	17	20.68
220 - 260	22	19.07
260 - 300	13	14.9
300 - 350	9	11.63
> 350	6	8.06
	Value of chi-square statistic	12.39
	Critical value at 90% confidence level	15.99

Table 5: Results of Chi-Square Goodness-of-Fit Test

Since the chi-square statistic is lower than the critical value, there is insufficient evidence at the 90% confidence level to reject the null hypothesis, hence using this Normal distribution is suitable for subsequent analysis.

2.3. Revenue Management

With estimates for the demand for season lots and for visitor lots, the tools of revenue management can be applied to achieve maximum revenue generation for the carpark. Specifically the tool used would be booking limits, which when applied to this project means limiting the number of season lots. The key parameters under this model are summarized in the following table:

Parameter	Description	Value
r_h , r_l	r_h: average daily revenue per non-season parking driver, the product of expected parking duration (hr) and the parking charge per hour ($1.6/ hr), which is $8 per day. r_l: average daily revenue from season parking holders.	$r_h = \$8\ per\ day$ $r_l = \frac{monthly\ season\ parki}{22\ weekdays}$
c_s , c_o	c_s: lost revenue by reserving more lots under season parking which could be occupied by the non-season parkers. c_o: lost revenue of an empty parking lot for non-season parkers which could have been reserved for season parkers.	$c_s = r_h - r_l$ $c_0 = r_l.$
α	α: critical fractile, also the probability that there is sufficient lots to meet demand for non-season parkers	$\alpha = \frac{c_s}{c_s + c_o}$

Table 6: Required Parameters of the Revenue Management Model

As discussed earlier in Section *2.2.2*, the high-priced demand can be approximated as a Normal distribution with mean $\mu = 200$ and standard deviation $\sigma = 98$. The optimal non-season parking lots can then be calculated as: $Q* = \mu + z\sigma$; however, as high-paying drivers is assumed to park for an average of 5 hours or half a day, a simplification was made, so that the number of lots needed to cater to high-paying drivers is $Q*\ /2$. Hence, the optimal season parking lots reserved is$(288-Q*\ /2)$. Subsequently, the optimal number of season parking lots and visitor lots is used to determine the expected revenue from both visitor lots and season lots, which takes into account the expected lost revenue as a result of insufficient supply of visitor lots. The following table presents the basic analysis for a range of price points for monthly season parking, between $55 where there is expected to be 100% demand for season lots and the current price of $90.

Monthly season parking price ($)	**50**	**60**	**70**	**80**	**90**
Price of season parking per day ($)	2.50	2.73	3.18	3.64	4.09
Optimal # lots to reserve as season lots	164	168	175	182	189
Optimal total revenue assuming all season lots sold	$1,852.44	$1,881.07	$1,937.10	$1,994.71	$2,052.35
% improvement from base case[2] assuming all season lots sold	57.23%	59.66%	64.41%	69.30%	74.20%

Table 7: Basic analysis assuming all season lots can be sold

As can be seen in the table above, the trend is that with a higher monthly season parking price, more lots need to be set aside as season lots, and also the optimal total revenue is higher as well. However this assumes that all season lots can be sold, which may not be the case in SUTD, since demand for season lots is assumed to be a linear function of monthly season parking price. As such, a modified version of the above analysis was done, with the added restriction that season lots were only available for the people of SUTD. The subsequent table shows how the demand for season lots and revenue generated changes with this added restriction.

Monthly season parking price ($)	**50**	**60**	**70**	**80**	**90**
Price of season parking per day ($)	2.50	2.73	3.18	3.64	4.09
% of demand for season parking from SUTD	100.0%	88.2%	73.4%	58.5%	40.6%

[2] The base case assumes that all season lots are sold at the monthly price of $90, generating a daily revenue of $1178.18.

Expected # of demand for season parking from SUTD (1)	222	196	163	130	90
Optimal # lots to reserve for season parking (2)	164	168	175	182	189
Expected number of season parking lots occupied by people of SUTD (Minimum of (1) and (2))	164	168	163	130	90
Optimal total revenue assuming all season lots sold	$1,852.44	$1,881.07	$1,937.10	$1,994.71	$2,052.35
% improvement from base case assuming all season lots sold	57.23%	59.66%	64.41%	69.30%	74.20%
Expected total revenue assuming season parking only for people of SUTD	$1,852.44	$1,881.07	$1,898.92	$1,801.98	$1,647.13
% improvement from base case assuming season parking only for people of SUTD	57.23%	59.66%	61.17%	52.95%	39.82%

Table 8: Subsequent analysis showing changes to revenue if season lots can only be sold to people of SUTD (Added rows in yellow)

A separate analysis was done with the current monthly season parking price and number of season lots, which produced an estimated daily revenue of $1866.25.

3. CONCLUDING REMARKS

3.1. Limitations

The main limiting factor in the analysis was in the quality of data obtained. Due to privacy issues, the main source of data was the number of entries into the carpark, aggregated only by day. As such, the actual demand from high-paying drivers had to be estimated based on a limited time study of the carpark.

Due to limitations of the chosen survey platform, we were unable to obtain demand data for more than 3 price points, as such the accuracy of the regression may be affected by the low number of price points.

3.2. Conclusion

Despite its limitations, the analysis for the revenue brings about interesting insight. With a higher season parking price, more lots should be set aside for season parking in order to maximize revenue, yet if the season parking lots are to be reserved solely for the people of SUTD, then it may be better to set a lower price instead so that more people would be willing to sign up for season parking and thus provide more revenue for the carpark operator.

Furthermore, it is noteworthy that the current estimated revenue generated by the carpark is relatively high compared to the estimated revenues as determined by the revenue management model used in this project. As such, while it can be said that the university is doing a relatively good job in setting the monthly season parking prices and number of season lots, this project has shown that it is possible to reduce the prices of monthly season parking passes and also increase revenue generated by the carpark. As such the team would like the university to strongly consider implementing a revised pricing scheme for season parking, as well as adjusting the number of season lots appropriately in the near future, so as to be able to generate more revenue from the carpark.

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REPOSITORY: Dumping Ground for things that not sure should put in or not

For the undergraduate and faculty / staff respondent groups, the F-statistic is greater than the corresponding critical value at both the 95% and 99% significance. Therefore, the null hypothesis is rejected and it can be concluded that at least one price point affects the willingness scores.

Undergraduate	Faculty / Staff
$55	$80
$65	$90
$85	$110

Table #: Price points used in the survey (yellow indicates current prices)

Undergraduate

Groups	No. of Data Points	Sum	Average	Variance
Current ($65)	43	87	2.02326	1.16611
Expensive ($85)	43	47	1.09302	0.13400
Cheaper ($55)	43	118	2.74419	1.95681

Table #: Summary of responses (Undergraduate)

Source of Variation	Sum of Squares	d.f.	Mean squared	F	P-value	F crit (95%)	F crit (99%)
Between Groups	58.93023	2	29.46512	27.14077	1.57912E-10	3.06810	4.77766
Within Groups	136.79070	126	1.08564				
Total	195.72093	128					

Table #: Results of ANOVA Single Factor Experiment (Undergraduate)

Faculty / Staff

Groups	No. of Data Points	Sum	Average	Variance
Current ($80)	76	260	3.42105	2.00702
Expensive ($90)	76	198	2.60526	1.70877
Cheaper ($110)	76	121	1.59211	1.01807

Table #: Summary of responses (Faculty / Staff)

Source of Variation	Sum of Squares	d.f.	Mean squared	F	P-value	F crit (95%)	F crit (99%)
Between Groups	127.6053	2	63.8026	40.43379	9.95E-16	3.03597	4.70073
Within Groups	355.0395	225	1.57795				
Total	482.6447	227					

Table #: Results of ANOVA Single Factor Experiment (Faculty / Staff)

- ***High and low fare customers*** The Carpark is facing two groups of customers: season parking (low fare customer) and the non-season parking (high fare customers). The high fare cost (rh) is the average daily revenue per non-season parking driver, the product of expected parking duration (hr) and the parking charge per hour ($1.6/ hr), which is $8 per day. While in the case of the low fare cost, since the season parking drivers are mostly staffs and faculties who drive to school mostly during weekdays, the average daily cost for low fare customers (rl) is determined to be the season parking fee per month divided by 22 working days a month on average.
- ***Shortage and Overage Costs*** The cost of shortage (Cs) should be the revenue lost by reserving more lots for the season parkings which could be occupied by the non-season parkers, hence, Cs = rh - rl. On the other hand, the cost of overage (Co) should be the lost revenue of the empty parking lot for non-season parkers which could be reserved for season parkers, hence, Co = rl. Therefore, the critical fractile can be calculated $\alpha = \frac{Cs}{Cs+Co}$.

Demand	Observed	Expected	70	80	90
0 to 50	100.00%	88.20%	73.40%	58.50%	40.60%
Expected demand for season parking from SUTD	222	196	163	130	90
Price of season parking per day	2.5	2.73	3.18	3.64	4.09
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