Title: Portland International Airport Parking Optimization

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EMP - P9010

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EMGT 543 PROJECT REPORT
SPRING TERM, 1990

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EXECUTIVE SUMMARY

This report analyzes the future short-term and long-term automobile parking demands at Portland International Airport to determine the minimum construction cost to meet this demand. By the year 2010, 704 additional short-term spaces and 3790 long-term spaces will be required to meet the expected 2.5 million additional travellers. This report found the minimum construction cost to be $34,570,000. This entails building 320 short-term spaces between the years 1995 and 2000. Long-term demand can be satisfied by constructing 1740 spaces between 1990 and 1995, 1740 spaces between 1995 and 2000, and 580 spaces between 2005 and 2010.

Limited real estate necessitated the need for multi-level parking structures for both short and long-term. Aesthetic and public inconvenience restrictions limited the physical size and construction timetable of these structures, respectively.

Simplifying assumptions were made to help the computer-aided cost optimization. First, the construction was limited to four five-year time periods. Second, inflation and interest rates were assumed equal. Third, the parking structures were to be built in modules with a fixed number of spaces.

This report integrated an EXCEL spread sheet and LINDO linear programming software package to mathematically minimize the total construction cost subject to the constraints outlined above.

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INTRODUCTION

Portland International Airport currently serves roughly three million passengers annually. The Ralph Burke master plan study (see attachment 1 for excerpts and Appendix D for the complete plan) performed in 1985 estimated that the number of passengers will be 5.5 million by year 2005. A correlation between the number of passengers and the number of required parking spaces was also made in the Burke study. Attachment 2 is a condensed version of future parking demands as the passenger enplanements increase from three million to levels approaching 5.5 million in 2005.

The demand curves for short-term (ST) and long-term parking (LT) were projected an additional five year increment to allow the planning effort of this project to account for four five-year time frames. Thus, the objective was to minimize the total cost of ST and LT parking facility construction and maintenance from 1990 to 2010. Economy long-term parking was also initially considered, but because no inter-relationships exist, economy was considered a separate project.

The Expansion Scenario

Short-Term (ST)

Attachment 3 shows a site plan of the current ST and LT parking arrangement. Due to the scarcity of real estate, both ST and LT multi-level structures must be built over existing LT surface lots to meet the increased demand. Attachment 4 shows the general growth pattern. A three level parking garage constructed in 1989 was positioned 200 feet west of the terminal building. It provided 1100 ST spaces on the second and third levels, while the rental car companies leased the first level. Pedestrian tunnels extend the entire width, and a pair of skybridges connect the structure to the terminal. The three level limit of the ST garage was imposed to maintain the current view of Mt. Hood from the terminal. Future expansions of the garage were logically restricted to modular three level increments. The module size was determined by the precast concrete structure geometry of 30 foot by 60 foot. This modular increment increases the capacity of the ST garage by 160 spaces while reducing the number of existing LT spaces by 54. One, two, or three of these modules could be built at any given time-frame. If three were built, the demand would be exceeded for the planning period.

Construction costs of ST expansion were derived from historical costs of the garage completed in 1989. The costs include a fixed cost of $328K that included engineering and contractor mobilization, and is independent of module size. A variable cost of $9000 per space was a contract cost which was obviously affected by module size. Maintenance costs were taken from accounting records and were computed to be $250 per space. Maintenance costs associated with existing spaces were fixed, and thus not useful as part of the objective function. Maintenance of a newly constructed module is not started until the time-frame

ATTACHMENT 1: **Enplanement forecast (number of travellers)**

TABLE 2I
PEAK AIRLINE ENPLANEMENTS AND OPERATIONS

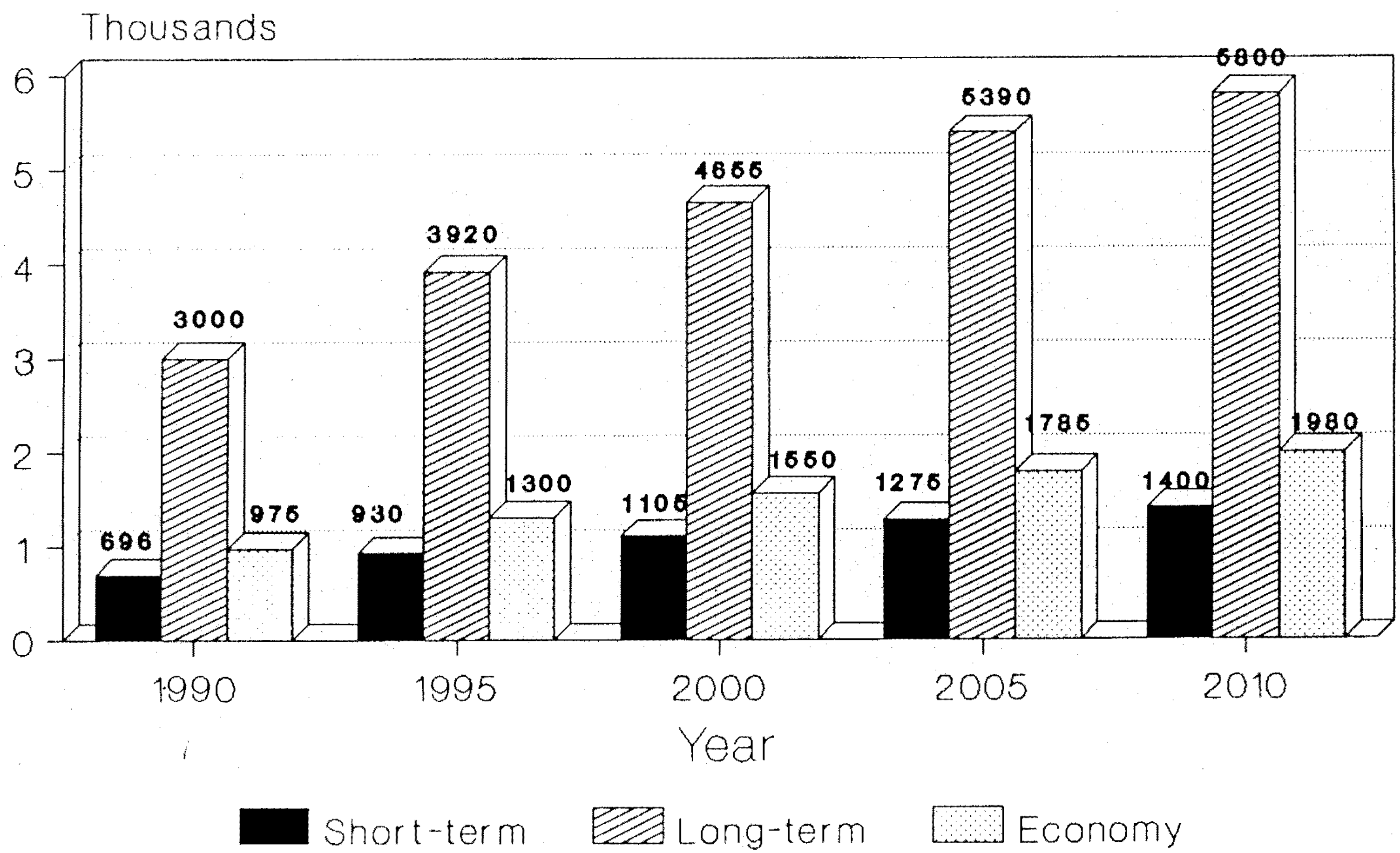
	1980	1981	1982	1983	1984
Enplanements					
Annual	1,931,573	1,851,080	1,967,991	2,263,821	2,363,339
Peak Month	195,401	174,075	192,520	226,720	240,960
Design Day	6,513	5,802	6,417	7,557	8,032
Design Hour	950	911	968	1,114	1,163
Month/Year	10.12%	9.40%	9.78%	10.01%	10.20%
Operations					
Annual	73,389	68,136	69,416	76,655	118,244
Peak Month	7,107	6,374	6,421	7,388	11,007
Design Day	237	212	214	246	367
Design Hour	24	21	21	25	37
Month/Year	9.68%	9.35%	9.28%	9.68%	9.31%

Forecast

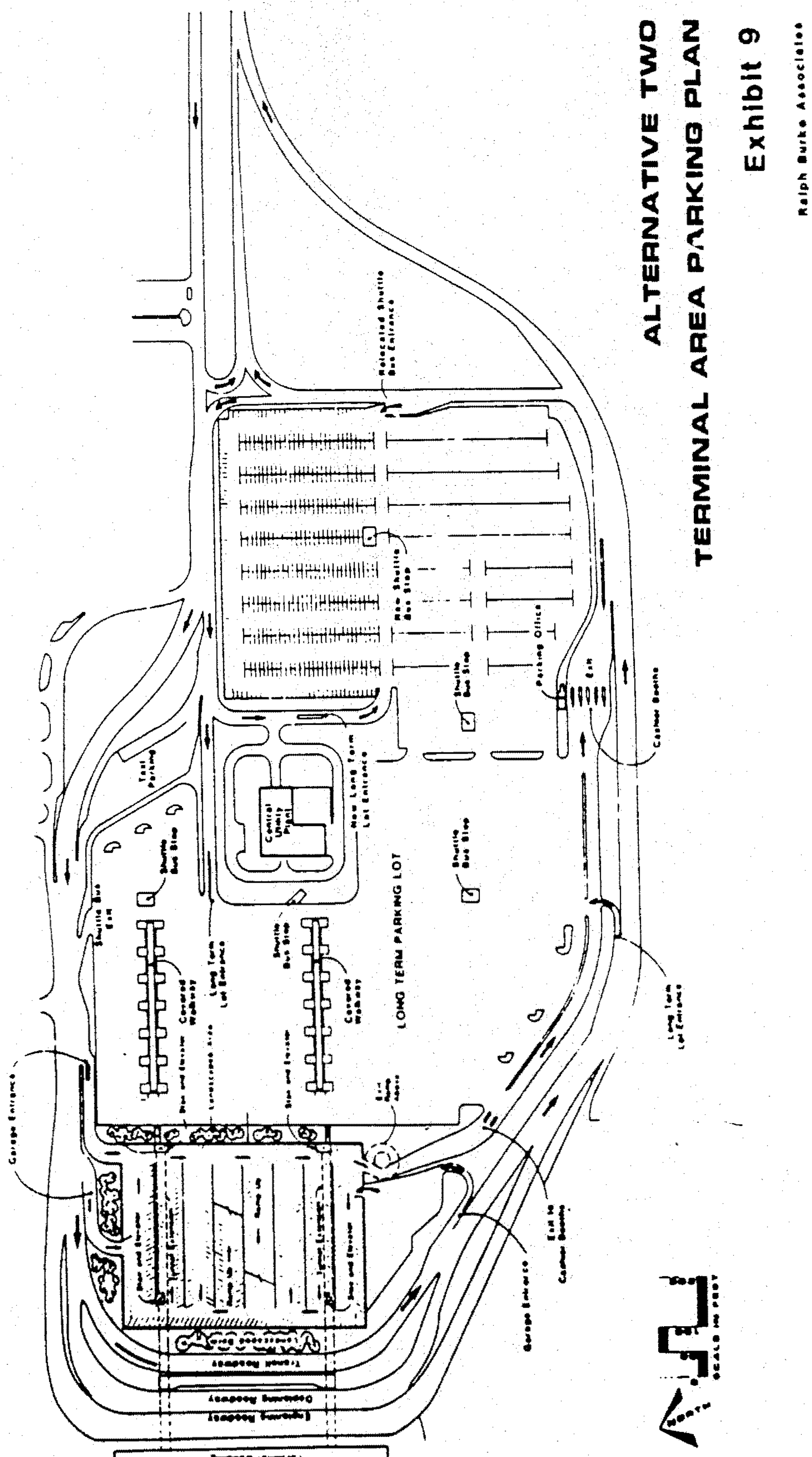
	1990	1995	2005
Enplanements			
Annual	3,000,000	4,000,000	5,500,000
Peak Month	297,000	396,000	545,000
Design Day	9,900	13,200	18,200
Design Hour	1,476	1,968	2,706
Operations			
Annual	131,012	169,426	232,790
Peak Month	12,446	16,095	22,115
Design Day	415	537	737
Design Hour	42	54	74

Attachment Two

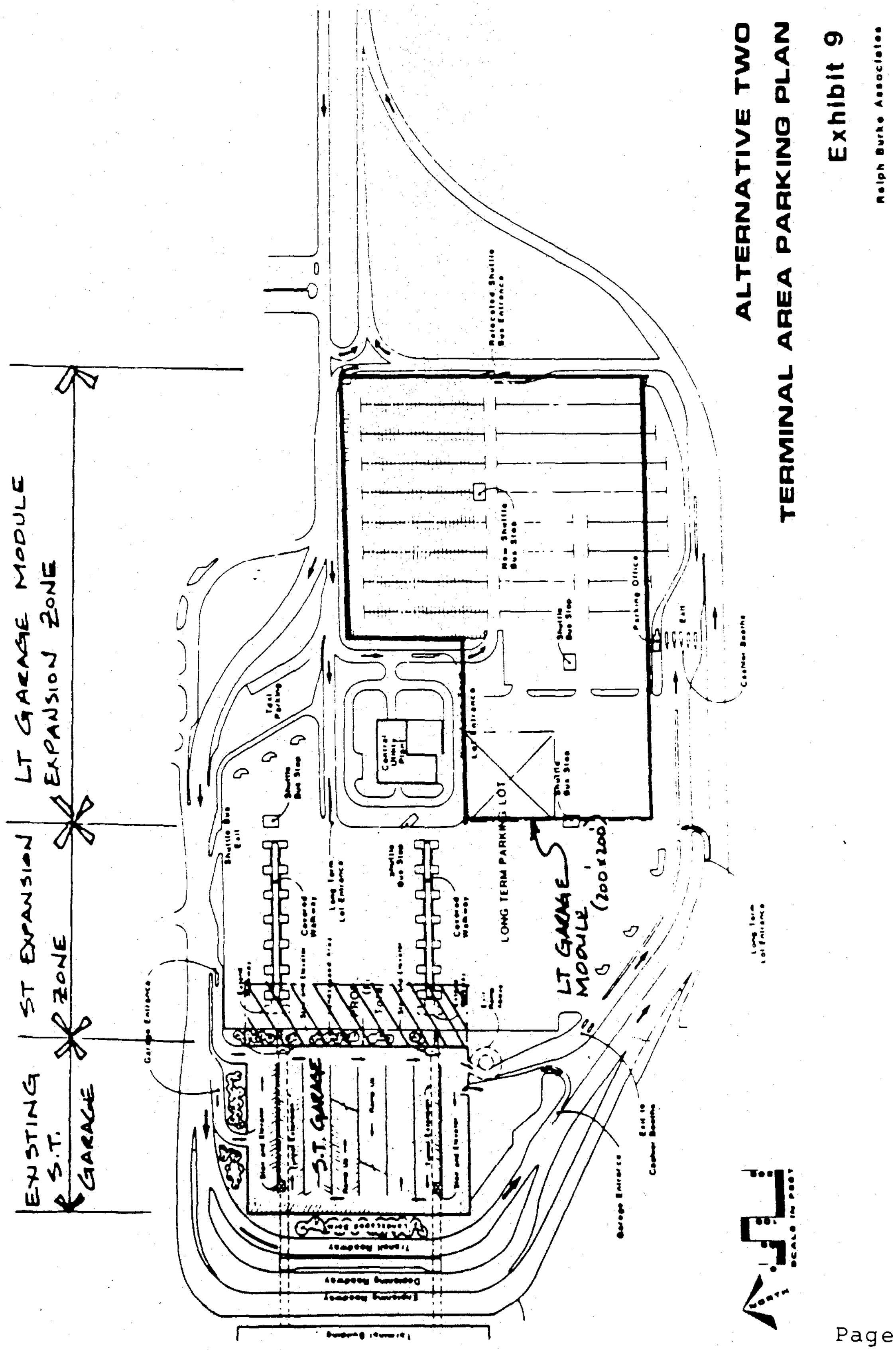
PARKING DEMAND



ATTACHMENT 3: Airport terminal parking plan



<u>ATTACHMENT 4:</u> Proposed parking expansion



following construction, because a new facility is warranted by the builder for a limited time. The initial observation made was that construction costs heavily outweigh maintenance costs.

Long Term (LT)

Demand for future LT parking exceeds the available real estate. The preferred expansion mode was to convert LT surface space (2200 spaces) to LT multi-level structures. Since the LT structure is farther from the terminal than ST, the height limitation was established at five levels to maintain the view of Mt. Hood. LT garage module size was not established, but the minimum conceivable module consumes approximately 40,000 square feet of surface area. This calculates to 580 (net gain) spaces per long term module. Up to four of these modules can be built before the planning period demand is exceeded.

Construction costs of the LT garage module were based on the historical costs associated with the ST garage. The LT garage was envisioned to be a "scaled down" version of the ST garage. Tunnels would be omitted, and the finish requirements would be reduced. Also, since five stories were permitted, the economies of multiple stories were estimated. When all manipulations were complete, a fixed cost of $280K, and a variable cost of $7K per space were established. Maintenance costs associated with LT were estimated to also be less than ST. A cost of $230 per space was used.

PROBLEM FORMULATION

The problem objective was to optimize a plan for the construction of Long and Short term parking spaces at Portland International Airport subject to the demand projections. The objective function was to minimize cost. The constraints and assumptions were as follows:

1) Time Periods.
This model was designed to span a twenty year construction period. For simplification the twenty years were broken down into four five-year sections.

2) Demand.
Demand projections were extracted from the Ralph Burke master plan study. The model was created so that demand must be met or exceeded for each five year segment.

3) Modular Garage Units.
The garage units are designed so that they could be built in a modular fashion. The number of spaces in a short term garage unit was 160. The number of spaces in a long term garage unit was 680 (gross). The long term garage consumed 100 existing spaces for a net long term space gain of 580 spaces. No partially constructed units were allowed.

4) Maintenance and Construction Costs
Maintenance costs were charged on existing spaces for each time period. The maintenance charges per five year period for ST and LT is $250 and $230, respectively. This is in keeping with current maintenance expense incurred today at PDX.

Construction costs were incurred whenever a garage module in short or long term was constructed. A discount for building more than one module at a time was included to reflect fixed costs being spread across a greater number of spaces.

5) Real Estate Shortage.
Due to the physical layout of the airport, the only way to gain short term parking was to use existing long term parking. For each 160 space short term structure built, 54 long term spaces were consumed.

6) Public Inconvenience
In order to avoid a large disruption in traffic at the airport the number of modular garage units in any period was limited. For short term, no more than three units were allowed to be constructed in any five year period. For long term, a four unit limitation was set.

7) Interest/Inflation Rate
The interest rate for money and inflation rates were set equal for model simplification. If these were not equal, the LINDO program would contain nonlinearities that would result in computational problems.

The integer format of this model caused the LINDO program run to be laborious and time consuming. Combined with a sensitivity analysis that would entail multiple "what if" LINDO iterations, a spread sheet was used in conjunction with LINDO to streamline the sensitivity analysis.

The decision variables were how may many spaces to be built in each five year period, subject to the constraints. The variables and meanings are as follows:

SA05 - one 160 short term garage unit built in the first five year period.
SB05 - two 160 short term garage units built in the first five year period.
SC05 - three 160 short term garage units built in the first five year period.
LA05 - one 580 long term garage unit built in the first five year period.
LB05 - two 580 long term garage units built in the first five year period.
LC05 -three 580 long term garage units built in the first five year period.
LD05 -four 580 long term garage units built in the first period.

These variables are then duplicated, changing the numerical value (05,10,15,20) for each of the next 3, five year periods. Thus, a total of 28 integer decision variables were used.

DETAILS OF MODEL

The spread sheet chosen was EXCEL by Microsoft. The output of EXCEL was "printed" in text only format to a file. The ability of LINDO to accept entries from an ASCII file formed a loose but workable data link. The cells of EXCEL were programed to make the necessary calculations and formatted to look like the Batch file syntax required by LINDO. The change of a single number in EXCEL, representing an assumption or raw data, ripples through the spread sheet, instantly forming new values for the nonlinear functions and automatically editing the model text. The line and column editing features of a spread sheet has proven to be a good interface for linear programming.

The Model-Building spread sheet is sectioned as shown in Appendix A. This first section contains cells where the definitions, assumptions, and data is defined. From this, the rest of the model parameters are constructed from these constants. The decision variables are boolean choices to build X spaces at a certain time.

The second section calculates construction and maintenance cost, then consolidates them into cost coefficients for the objective function. The construction costs are segmented for Short Term structures and Long Term Facilities. The construction discounts come from the amortization of fixed costs over the number of units built. Consideration of inflation and interest rates only added uncertainty to the optimization of a long term plan. If one wished to use present values in the calculation, it would expand the single row labeled C-Cost into 4 rows. The group decided this complexity added neither accuracy or academic value to the model and thus was dropped. Since time was not considered in the formula for construction cost, the formula consisted of the fixed cost divided by the chosen number of spaces to construct, added to the variable cost and then multiplied by the number of desired spaces.

A reasonable assumption was made to neglect any maintenance cost during the period of construction. Therefore, the maintenance formuli are simply the chosen number of spaces, times the cost of maintenance per period, times the number of periods remaining in the 20 decision span.

The sum of construction and maintenance costs is in a separate array for clarity. These values are directly mapped into the Objective Function shown under the word MINIMIZE. They were divided by 10 simply to get the row format chosen to fit within 80 characters.

The third section dealt with constraints. Since this was a plan for the future, the past was merely a relative origin. The forecast of total spaces needed in the future was adjusted to eliminate existing spaces.

The fourth section of the "model builder" spread sheet formatted the numbers calculated in prior sections so that LINDO would accept them as a linear model. The spread sheet had optional formatting capability which allowed for prefixing the number with plus or minus symbols as well as displaying zero's. For rapid comprehension and duplication, each row has identical format. The numerical constraints are defined in linear model rows (2) through (9). The remaining part of the model is the exclusive selection of either ST or LT for each time period. Refer to Appendix A for a copy of the linear programming model.

SOLUTION

Appendix B shows the optimum LINDO output. The optimum value for the objective function is $34,570,000. This represents the minimum cost to construct parking facilities to meet the expected demand. This optimum value is derived from the following solution:

1) Build 1740 LT spaces (three modules) in the first period;
2) Build 320 ST spaces (two modules) in the second period;
3) Build 1740 LT spaces (three modules) in the second period;
4) Build 580 LT spaces (one module) in the fourth period.

Appendix B shows the LINDO output for the optimum solution.

SENSITIVITY

Five areas that could affect sensitivity of the model were reviewed. In each case the input was varied to see what, if any, effect the different data had on the outcome.

The first area looked at was the estimated construction cost. The initial costs were drawn from historical data . To test the sensitivity the construction costs were changed plus or minus 100% with no movement in the optimum solution. Increasing the construction cost was equally fruitless. The optimum solution remained unchanged.

The second area investigated was the area of maintenance cost.

Since these costs are trivial compared to the construction costs a reduction in maintenance cost was not considered. The original estimate was based on historical data. The estimate was increased twenty five percent and again found no effect on the solution.

The third area considered was the effect of inflation. The original estimate ignored the effect of inflation. Since the time value of money and the inflationary tendencies move at a similar rate it was figured the effect of one would be offset by the effect of the other. In fact considering inflation simply pushed all the construction into the earliest possible window. The optimum solution increased as the inflation increased the construction costs in each successive period. As soon as the inflation costs exceeded the maintenance costs the solution to the model changed to reflect the dominance of the cost due to inflation.

The one area that proved to be most sensitive is the area of predicted demand. The original estimates were based on a study commissioned by the Port of Portland to provide the information needed to do the long range planning. Since parking demand must be satisfied, the solution changes when the demand exceeds allotted spaces. For instance, in the original model, the first period has a projected surplus of short term spaces, It the projection is modified to the point where the surplus disappears, the construction that was slated for the second period in the optimum solution is moved into the first period, It follows that if the predicted need for added spaces in the second period is altered to a projected surplus in the period. The model exhibits its' greatest sensitivity in the area of the predicted demand. Specifically, the model changes with a plus or minus one percent change in demand.

The other area investigated for sensitivity was construction constraints. These constraints require that the spaces be built in modules. For short term, the module size was 160, 320, or 480 spaces. For long term, module size was 580, 1160, 1740, or 2380 spaces. These constraints are real as the number of spaces per floor and the number of floors are physically restricted at the airport. A change in these criteria does have an effect on the optimum solution since demand must be met. Specifically, the optimum solution changes when the structure size was changed plus 17% and minus 8%.

To summarize the investigation, the model was highly insensitive to each of the areas researched except for the demand projections and the construction constraints. The demand predictions are the dominating data and should be the recipient of the of the most interest. The construction criteria networks with the demand to select the solution. The accuracy of this data is critical to assuring the solution is optimum. Appendix C contains multiple LINDO runs used in the sensitivity analysis.

SUMMARY

This report minimized the cost of constructing short-term and long-term parking facilities to meet increasing demand at the Portland International Airport. Due to limited real estate, parking structures for both ST and LT are required. Other limitations included a need to minimize public inconvenience by limiting the amount of construction at any one time, as well as an aesthetic restriction on structure height to maintain a view of Mt. Hood from the airport terminal.

Three simplifying assumptions were made. One was to break the 20 year demand forecast into four five-year increments. Second, inflation and interest rates were set equal to eliminate their nonlinear contribution to the LINDO optimization program. Third, the parking structures were defined to be built in modules as is common construction practice.

Based on this information, the minimum cost to construct parking facilities to meet the expected demand is $34,570,000. LT spaces are to be built in the first, second and fourth five-year period, while St demand will be satisfied with construction in the second period only.