1-1-1996

Cost Scale-Up Factors for Airport Construction

Donald S. Remer
Harvey Mudd College

Christopher Wong '96
Harvey Mudd College, Claremont McKenna College

Recommended Citation

Remer, D.S. and Wong, C, "Cost Scale-Up Factors for Airport Construction," Cost Engineering, 38, 2, 24(1996).

Cost scale-up factors for airport construction
Remer, Donald S;Wong, Christopher
Cost Engineering; Feb 1996; 38, 2; ABI/INFORM Complete
pg. 24

Cost Scale-Up Factors for Airport Construction

Dr. Donald S. Remer, PE, and Christopher Wong

Engineers must often make a quick "ballpark" cost estimate of a new plant, facility, or piece of equipment before the detailed design phase. One easy way to obtain such an estimate is to base the cost on a known cost for a similar plant, facility, or piece of equipment by using the ratio of the capacities or sizes of the known and proposed item raised to an exponent *R*.

This predesign cost-estimating approach is especially useful for doing sensitivity analyses and feasibility studies for which a high degree of accuracy is not required. This cost-capacity or power-factor model was first developed by Williams in 1947 for equipment costs [7] and by Chilton in 1950 for plant costs [1].

In this article, we present scale-up factors for estimating the costs of terminal expansions to existing airports in the United States and the costs of constructing new international airports.

THE POWER-FACTOR MODEL

The cost and size of certain types of equipment or facilities are related by the power-factor equation

$$\frac{\text{cost}_2}{\text{cost}_1} = \left(\frac{\text{size}_2}{\text{size}_1}\right)^R$$

where
R is the exponent or cost-capacity factor that is determined empirically.
(equation 1)

The *R* factor can be determined by taking the logarithm of both sides of equation 1 to obtain the following expression:

$$\log\left(\frac{\text{cost}_2}{\text{cost}_1}\right) = R\log\left(\frac{\text{size}_2}{\text{size}_1}\right)$$

(equation 2)

Equation 2 indicates that if one plots the cost versus size on a log-log scale, the slope of the line determined by a least squares analysis will be the *R* value. (This is simply a linear expression like $y = mx$, when plotted on a log-log scale.)

Equation 1 also implies that for *R* values near one, increases in size correspond to a one-to-one increase in cost. For example, doubling the size doubles the cost. However, for *R* values greater than one, doubling the size more than doubles the cost, thereby signifying a diseconomy of scale. Similarly, an *R* value less than one means doubling the size requires less than double the cost, which represents an economy of scale.

Many *R* factors have been reported to help cost estimators do quick ballpark calculations. The *R* values for over 200 types of process plants (primarily in the chemical industry), such as ethylene or sulfuric acid plants, have been presented [4], as have the *R* values for scaling up over 75 types of process equipment such as heat exchangers, fluid-moving equipment (blowers, compressors, fans, and pumps), tanks, vessels, and towers [3]. Other researchers have provided cost-estimating *R* factors for 58 kinds of biopharmaceutical process equipment, including newly-reported values for autoclaves, freeze-dryers, fermenters, and water purification systems [5]. These new values were developed by performing cost estimates for several prospective bioprocess plants for recombinant proteins.

Recently, the cost estimating *R* factors for air-pollution control equipment, including particulate-control devices, gas-control devices, and auxiliary equipment such as cyclones, ductwork, and stacks have also been summarized [6].

This article illustrates how to develop *R* factors for airport construction. The next question is which parameter should be used for the variation in size. For airports there are several possibilities: potential capacity in terms of passengers per year, the area of the airport, and the number of gates. Increasing any of these factors should lead to an increase in the cost of construction. The way to determine the best variable is to make a log-log plot using actual data and calculate the best-fit line through the data points. The scale-up parameter to use would have the coefficient of determination closest to "one" for the best straight-line fit of the data.

BUILDING ADDITIONAL AIRPORT TERMINALS

Recently, many airports in the United States have undergone or are undergoing expansions by building more terminals; these airports are listed in table 1. The costs have been normalized by location using the 20-city average **Engineering-News Record** construction cost index for June 1994 [2].

Data on the area of the terminal, the number of gates, and the capacity measured in passengers per year were obtained. Each of these size variables was then plotted versus cost on a logarithmic

Table 1—Recent US Airports That Have Added Terminals

Airport	*Location*	*Date of Operation*	*Terminal Cost (millions 1994 US $)*
O'Hare	Chicago	5/93	557
JFK	New York	1998	299
Newark	New York	fall 1995	75.6
Hartsfield	Atlanta	9/94	478
Colorado Springs	Colorado	10/94	52.1

plot. The slope of the best-fit line using a least-squares regression analysis is the *R* value. Of the three parameters, terminal area gave the best fit, as shown in figure 1.

The *R* value for the graph is 1.2, and the coefficient of determination is 0.95. A value close to one means that the data points essentially fall on a straight line. When calculating cost estimates for building airport terminal expansions, an *R* value of 1.2 can be used in equation 1.

This *R* value was obtained for terminal areas ranging from 0.25 to 1.6 million ft^2 (0.023 to 0.15 million m^2). We do not recommend using this *R* value for airport terminal expansions outside of this range because we do not know if the cost of such expansions follows the same trend; the *R* value is obtained purely from empirical data.

BUILDING NEW INTERNATIONAL AIRPORTS

The Denver International Airport is the only commercial airport built in the United States in the past 20 years. New international airports, most of them located in the Pacific Rim, provide data for calculating *R* values for building a grassroots airport. Table 2 lists international airports that have been built recently or will open in the near future. The nominal costs are listed because normalizing them with respect to consumer price indexes for each individual country changed the resulting *R* factor by less than 1 percent.

Logarithmic plots of cost versus each size parameter, the area of the entire site, the number of gates, and capacity were plotted. Passenger capacity, shown in figure 2, yielded the best correlation.

The *R* value for this graph is 2.9, with a coefficient of determination of 0.93. This cost capacity *R* should not be used far outside of the capacity range of 10 to 35 million passengers per year. Several of these airports have not been completed, so actual costs may be higher. This would increase the *R* factor. Table 3 summarizes the *R* values obtained for the expansion of US airport terminals and for new international airports.

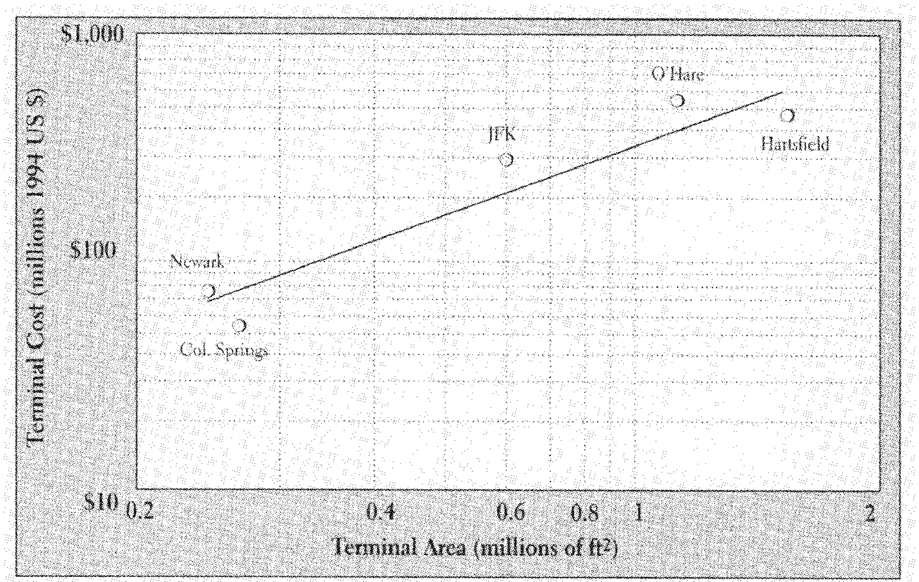


Figure 1—Cost Versus Area for US Airport Expansions (Log-Log Plot)

Table 2—New International Airports

Airport	*Date of Operation*	*Cost (billions 1994 US $)*
Hong Kong	mid-1997	20
Seoul	1999	4.88
Denver	2/28/95	4.9
Bangkok	1999	4
Kuala Lumpur	1998	3.4
Osaka (Kansai)	9/4/94	15
China (Zhuhai)	3/95	0.47
Manila	1998	0.40

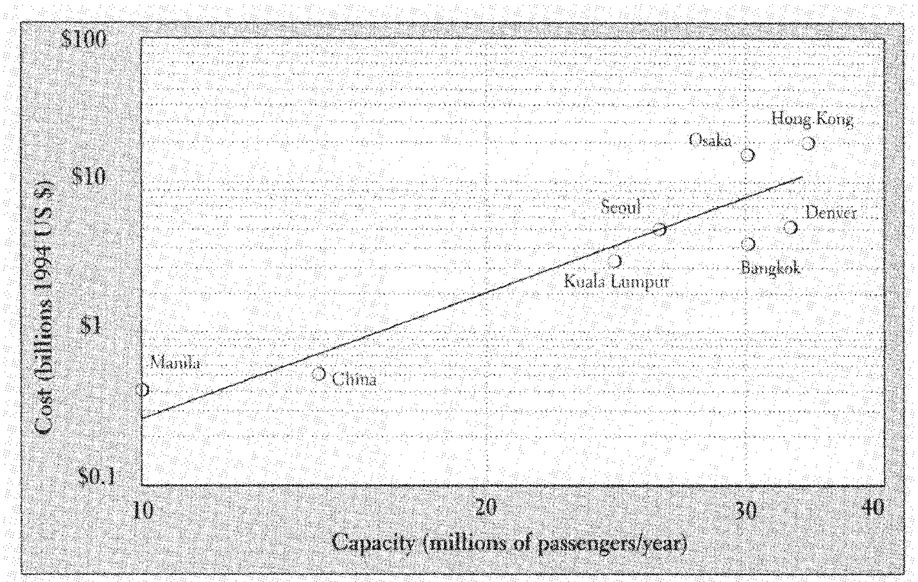


Figure 2—Cost Versus Capacity for International Airports (Log-Log Plot)

MAKING COST ESTIMATES

Suppose a new terminal covering 1 million ft^2 (0.093 million m^2) is to be added to the existing Dallas/Fort Worth Airport in 1994. What is a quick "guesstimate"?

Finding the cost using the power-factor model requires the cost of a similar terminal. Suppose the new terminal is structurally similar to that of O'Hare's terminal, which has an adjusted cost of $557 million and an area of 1.14 million ft^2 (0.106 million m^2). Using equation 1 and the *R* value of 1.2 derived earlier, the adjusted cost of Dallas's new terminal is

$$C_{Dal} = C_{Chi} \left(\frac{A_{Dal}}{A_{Chi}} \right)^{1.2}$$

$$C_{Dal} = \$557 \text{ million} \left(\frac{1 \text{ million ft}^2}{1.14 \text{ million ft}^2} \right)^{1.2}$$

$$C_{Dal} = \$476 \text{ million.}$$

(equation 3)

To find the actual price in Dallas, multiply the result by the ratio of the **ENR** cost index for Dallas to the **ENR** 20-city cost index, which gives a cost of $334 million. An inflation adjustment for 1993 and 1994 also would have to be included. The prices calculated using this model are only a rough estimate—be sure to account for any unusual circumstances. For example, one would expect Denver's cost of construction to be high because of the start-up problems with the baggage transport system.

Actual vendor quotations and detailed cost estimates are extremely important, but for quick estimates, the *R* factor method is very helpful for approximate results. Keep in mind that the specific airport location may greatly influence the final cost. For example, the Osaka Airport is located on an artificial island. This project went 50 percent over the original budget.

We hope readers will send us any *R* values they develop so we can periodically prepare compilations of *R* factors [3, 4, 5, 6].

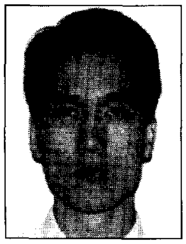
Table 3—Summary of Cost Capacity R Factors

	Size Parameter	Cost Capacity R Value	Coefficient of Determination	Range
domestic airport expansion	terminal area	1.2	0.95	0.25-1.6 million ft² (0.023 to 0.15 million m²)
international airport construction	capacity	2.9	0.9	10-30 million passengers/year

REFERENCES

1. Chilton, C.H. *Six-Tenths Factor.* **Chemical Engineering**, April 1950, 112-114.
2. *Market Trends.* **Engineering-News Record**, June 18, 1994, 70.
3. Remer, Donald S., and L.H. Chai. *Design Cost Factors for Scaling-Up Engineering Equipment.* **Chemical Engineering Progress**, August 1990, 77.
4. Remer, Donald S., and L.H. Chai. *Estimate Costs of Scaled-Up Process Plants.* **Chemical Engineering**, April 1990, 138.
5. Remer, Donald S., and J.H. Idrovo. *Cost-Estimating Factors for Biopharmaceutical Process Equipment.* **Bio-Pharm**, September 1990, 36.
6. Remer, Donald S., Becky I. Low, and G. Thomas Heaps-Nelson. *Air-Pollution Control: Estimate the Cost of Scaleup.* **Chemical Engineering**, November 1994, 11.
7. Williams, R. *Six-Tenths Factor.* **Chemical Engineering**, December 1947, 124-125.

***Dr. Donald S. Remer*, *PE*, is the Oliver C. Field Professor of Engineering at Harvey Mudd College of Engineering and Science in Claremont, CA. Dr. Remer received his B.S. in engineering from the University of Michigan and his M.S. and Ph.D. from the California Institute of Technology in engineering, with a minor in business economics. He is a partner and a cofounder of the Claremont Consulting Group, which specializes in cost estimation, project economics, systems engineering, management, and the training of engineers, scientists, and managers in these areas via short courses.*



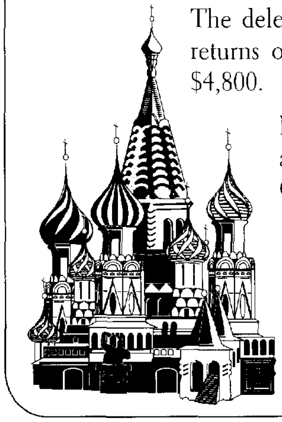
***Christopher Wong** is an undergraduate engineering student at Harvey Mudd College. He is also fulfilling an economics degree at Claremont-McKenna College. His interests are in communications and in combining his business background with his technical skills.*◆

Attention AACE International Members!

A delegation of engineers and professionals involved in cost estimating on engineering, construction, and other large projects is being organized to exchange information with counterparts in Russia and Poland. The program is being arranged under the auspices of the Citizen Ambassador Program of People to People International.

You will be receiving letters from Larry G. Medley Sr., CCC, Past President, and John H. Luppert inviting you to join this delegation.

The delegation will travel to Moscow, St. Petersburg, and Warsaw to get an insider's view on local projects and to help establish links between cost professionals in different countries.



The delegation leaves New York, NY, on April 12, 1996, and returns on April 25, 1996. The estimated cost per person is $4,800.

If you would like more information about this once-in-a-lifetime opportunity, contact Larry G. Medley Sr., CCC, at 423-576-5824 or

AACE International
209 Prairie Ave./Suite 100
Morgantown, WV 26505
Phone: 800-858-COST/304-296-8444
Fax: 304-291-5728
E-mail: 74757.2636@compuserve.com