Staging Runway Expansion by Dynamic Programming for Washington National and Dulles International Airports

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A time-staging decision for a long-range runway expansion program has been developed by adapting the dynamic programming methodology to economic optimization for a given planning horizon. Specifically, major efforts are made to bring the model into a highly useful form and to further tie the theoretical concept to the working reality by testing the model on real-world examples. Washington National Airport and Dulles International Airport were selected as test cases. The results showed that National could best be served by adding a fourth runway and that Dulles already has too large a runway capacity for its air traffic demand. Viewed in a multiairport perspective for the Washington, D.C., metropolitan region, the possibility of improving both airport operations by shifting some portion of National's demand to Dulles was indicated. A thorough evaluation of the methodology and its applicability revealed that the developed model should be capable of greatly benefiting the planning of airport runway operations.

The relatively new mode of air travel has grown steadily to the point at which it is now indispensible in the public's mind. Its maximum range has grown as quickly as the development of airport facilities and the furthering of air technology have allowed. Today, air traffic congestion at the major airports is considered to be the most critical problem of air transportation. Because of the complicated mixture of authority and interest inherent in the airport organization, including governments, commercial carriers, and the general public, planning of the airport for relief of traffic congestion can become a highly difficult process. As with most transportation facilities, airport planning is an attempt to best meet the needs of demand with a limited financial resource.

The problem facing the airport planner is assessing the operating and maintenance costs incurred by the current facilities and attempting to balance the costs of improving these facilities. The basic objective is to minimize the overall costs to 3 sectors: airport operator, aircraft owner, and aircraft passenger. Both aircraft operators and passengers bear costs incurred by delay of arrival or departure of airplanes. The air passenger typically values his or her time more highly than the passenger on other major modes, reflecting the perceivable benefit that air travel holds in the form of reduced travel time. When delays are excessive, this cost plays a far more significant role and leads to a drop in demands due to dissatisfaction with air service. The operator, faced with fuel, wage, and maintenance cost increments due to terminal delay, is sensitive to the value of time. All 3 segments of this airport problem must live with the time value of money itself, which is expressed economically as land value, growth rates, and interest rates. These, then, are the cost factors directly associated with runway planning.

For reducing air traffic delay costs, a runway configuration expansion is an appropriate consideration. A total analysis of the interactions of the cost factors previously described obviously should be carefully made. But, because of the complexity of runway planning and the amount of money involved, the tools of analysis that are available to the planner are insufficient.

The objective of this study was to introduce a factual and practical guideline relating to the timely development of runway configuration. This guideline was developed as a time-staging decision model that accounts for all cost factors that should be properly involved in deciding on improvements. Furthermore, the emphasis was on bringing the developed model into a highly useful form. With much of the conceptual groundwork apparently complete, tying the theoretical concept of the model to the working reality of today's planning situations was vital.

PREVIOUS WORK ON METHODOLOGICAL DEVELOPMENT

An investigation was initiated to determine how to best schedule runway configuration improvements for planning and design purposes (1, 2). A brief review of this previous study is necessary to indicate the theoretical framework on which the current study was based.

As indicated, the costs involved in runway configuration decisions include many factors relevant to airport users, both passengers and aircraft owners, as well as

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to aircraft operators. These costs are of 2 types. The first is capital costs, which are those directly related to configuration and include land acquisition costs, land preparation costs, facility construction costs, and salvage values. The other type of cost is annual or cash flow costs, which include those costs connected with the use of a given configuration over a period of time and encompass items such as runway maintenance, aircraft delay costs, and passenger delay costs. The time value of money, interest, is a substantial cost in the scope of a long-range planning period, and will affect the optimal timing of a runway improvement. The incorporation of time cost of money necessitated a means of comparing funds on an equivalent basis.

The solution technique selected for analyzing this cost problem was dynamic programming. By putting all costs throughout the planning period on a present worth cost (PWC) basis, we derived 2 major types of costs. One is the cost of maintaining operations on a given configuration for an additional year, and the other is the cost of making the transition from one configuration to another. These 2 types of cost correspond directly to the change-of-stage and change-of-state quantifiers in dynamic programming formulation. They establish a latticed network of possible economic decisions through which the optimal path (or course of actions) can be found by the dynamic programming method. The optimal solution is that which yields the least costly path through the latticed network.

A concern with the practicality of using such a model for real analysis dealt with the difficulty in quantifying some of the necessary parameters, such as interest and growth rates, over a long planning period. Deviations from assumed values could alter the optimal expansion plan. To handle this difficulty, the program was designed with a built-in sensitivity analysis capability. Results can be produced in a single run for a large range of combinations of parameter estimates, allowing the programmer to check the sensitivity of the solution to changes in estimated parameters. Deviations in cost estimates, although affecting the total costs of alternatives, did little to alter the relative ranking of alternatives. The complex web of cost interactions necessitated a stage improvement model, rather than a rule of thumb, for proper decisions by planners. In addition, the planning program as developed was tested on a number of hypothetical runway configuration planning problems that were fabricated to illustrate not only the versatility and workability of the decision model but also the utility and applicability of the entire package in an actual planning situation. For the problem as formulated, the dynamic programming approach was suitably efficient for computation.

The computer program that has been developed for analyzing the runway expansion problem by using the described time-staging decision model has 3 major functional stages as shown in Figure 1. The first stage in execution is the use of data concerning operations level and flight delay to determine a functional relationship between these 2 variables. Data and analysis, by means of polynomial regression techniques, are necessary for each alternative configuration.

After the delay model has been constructed, its results are combined with the second half of the data deck. This group of cards defines the economic characteristics inherent in the runway configuration alternatives and the airport in general. This information is used by the second program stage, which calculates the component costs related to aircraft and passenger delay, construction maintenance, land costs, and salvage factors. It also performs the dynamic programming search for the least costly expansion program.

The final functional stage is the arrangement and printing of the results in such a form that they are ready aids to the decision-making process. Emphasis is placed on visually descriptive output forms and on completeness of possible output.

The program is capable of handling an economic analysis with a planning horizon of up to 20 years and up to 10 alternative configurations. The 10 alternatives, including the current or base configuration, must be ranked in order of increasing capacity or efficiency.

Within the above framework, the program can accommodate many cost parameter variations in the sensitivity analysis. The limits as written are as follows: 5 land value growth rates, 5 construction costs, 5 estimates of operations growth rates, and 6 interest rates. In addition, 3 salvage value determinations are built into the analysis. Although this number can be easily expanded, it should be remembered that the previously mentioned limits would allow for examination of 2250 different parameter combinations in 1 analysis.

Further documentation of the previous work is available elsewhere (1, 3).

APPLICATION TO WASHINGTON, D.C., AREA AIRPORTS

To check and to demonstrate the utility of the developed model, we selected 2 existing major airports, Washington National Airport and Dulles International Airport, both of which serve the Washington, D.C., region, for this study. A number of considerations were involved in the selection of these airports. They are both major air terminals. Their designs and operations contrast sufficiently to demonstrate the versatility of the computer model, yet the airports, though contrasting, serve the same area, which allows for an investigation of the use of the model in analyzing a multiairport situation. Furthermore, the gathering of data on alternative configurations and other economic factors, though not a simple process, was facilitated by selecting these airports because of their proximity, close cooperation, and the fact that a single agency, Metropolitan Washington Airport Service (MWAS), a division of the Federal Aviation Agency, operates the 2 airports. Both historical and predictive data covering the period from 1964 to 1983 were collected for both Dulles and National airports.

The difficulties involved in data collection for this study tend to reveal how innovative this form of analysis technique is in the airport planning field. Data collection involved personal contacts with many offices of federal and local government. In addition, a questionnaire was designed and sent to MWAS.

Two basic types of data were necessary—those related to the determination of capacity and delay and those related specifically to the various economic cost factors required as program input. Portions of the data body had to be estimated and thus may not be as accurate as the remainder. The sensitivity analysis feature of the program proved highly valuable in confirming the reliability of the results based on these estimates by establishing the stability of the solutions.

Capacity and Delay Data

Of prime importance in calculating delay costs is the preliminary analysis necessary to ascertain the operating characteristics of all the proposed configurations. To accomplish this objective, we used the Airport Capacity Handbook (4). A wind rose showing the percentage of time that the wind blows in a particular direction and at a particular velocity was used to develop runway use patterns. MWAS was able to supply the National wind rose. That for Dulles was obtained from the Data Processing Division of the U.S. Air Force Weather Service.

After obtaining data on exit locations and types from airport master plans and knowing runway use and aircraft mix at each airport, we could determine average runway occupancy times. An additional factor involved was the amount of time that operations were under instrument flight rules (IFR) and visual flight rules (VFR) because this affects the aircraft mix. Occupancy times could then be transformed into configuration capacities from which delays at certain operation levels could be calculated. As shown by the data given in Table 1 (5), the operations levels selected cover the years 1964 to 1983, which spans historical and projected demand.

Economic Data

After the magnitude of delay is known, the cost of that delay can be found by using appropriate unit cost factors for aircraft operation and passenger time values. Aircraft delay costs were obtained from 2 sources, the Civil Aeronautics Board (CAB) (6) and Airborne Instruments Laboratories (4). The costs were used in conjunction with the aircraft mix data for National and Dulles airports to establish weighted average costs for both airports.

The valuation of passenger travel time is a complex area of study. Values for an hour of a passenger's time range over a wide spectrum. Most are based on a relationship to the wage rate of the passenger. Although travel time values ranged from \$5.78/h (21) to \$14.00/h (7), more typical estimates include \$7.28/h (8) and \$8.09/h (9) for coach passengers and \$11.97/h (9) for first-class passengers. The Warshow study (7) uses a weighting formula of 1.5 times the wage to determine the value of business travel time, and uses 0.5 as a factor for personal travel. By applying this formula to the average value of \$5.78/h mentioned above, we obtained a weighted value of \$7.88/h for use in this study. Average passenger loads for aircraft were derived from the MWAS questionnaire results.

Because current land values were not available, estimates had to be obtained from the Real Estate Assessor's offices of Arlington and Fairfax Counties. For National Airport, these values were \$151 to \$161/m^2 (\$14 to \$15/ft^2). For Dulles Airport, they were \$11/m^2 (\$1/ft^2). The 1963 land value for Dulles Airport was obtained from MWAS based on the acquisition cost and was \$1.78/m^2 (\$0.16/ft^2). The approximate rates of growth in land value were 26 percent for Dulles Airport and 5.5 percent for National Airport based on the county estimates.

Construction costs for Dulles Airport came from MWAS information. The total cost of the 3 Dulles runways and their taxiways was \$20.7 million, or approximately \$8.29 million per single runway. For National Airport, no actual costs were available; therefore, estimates of \$30 to \$36/m^2 (\$25 to \$30/yd^2), obtained from the firm of Howard, Needles, Tammen and Bergendoff of Alexandria, Virginia, were used. The higher figure accounts for heavier jet aircraft.

Setup costs are those 1-time costs associated with construction, such as machinery transfer. They essentially include all nonadditive costs if 2 or more improvements are built simultaneously. The estimate used for setup costs was 10 percent of the overall construction costs. Maintenance costs were derived from the operating budgets for the 2 airports in their current state.

The final cost consideration is the time value of money as expressed by the interest rate. Rates selected for use included 10 percent based on the prime interest rate, 8 percent based on local government bonds, and 6 percent based on local bank rates. Sensitivity analysis was performed around these figures.

ANALYSIS OF WASHINGTON NATIONAL AIRPORT

A time-staging decision model was first used to analyze potential improvements to the runway configuration of National Airport. The existing configuration for National Airport was considered the null case. The basic alternatives that were investigated are shown in Figure 2. Table 2 details the physical plant costs involved for each alternative. Delay data figures are given in Table 3.

As has been previously discussed, the improvement configurations fall into 2 possible expansion series. The first involves upgrading the current layout by means of high-speed exits and addition of a fourth runway. The other program of improvement (the remaining 3 alternatives) relies on developing an additional land area for new runway construction. The result of this program would be a parallel duplication of the current configuration of National Airport.

An evaluation of the entire 20-year period from 1964 through 1983 was conducted to study the long-range evaluation of the model. This 20-year plan could be compared with the preferences indicated by 2 consecutive 10-year runs, one from the planning viewpoint of 1964 and the other from the planning viewpoint of 1974. The 20-year analysis results revealed that the cost of upgrading the existing runways by adding high-speed exits would not be entirely counterbalanced by reduced delay costs. As currently operated, Washington National Airport is crowded, yet it is an efficiently run system. The additional efficiency possible through a high-speed exit improvement program is not that significant. However, a combination of high-speed exit improvements and the addition of a dual runway in 1964 would have significantly aided the overall cost incurred by operation. Table 4 gives the 20-year analysis results for Washington National Airport. The modification factors for the data in Table 4 are as follows:

1. Interest rate of 8 percent,
2. Operation growth of 0 percent,
3. Land value growth of 5.5 percent,
4. Construction factor of 1.00, and
5. Salvage factor of 1.00.

As shown by the data, the savings over the 20-year period would have accumulated to about \$33 million in present worth terms for 1964. The increased construction and maintenance costs would be offset by reduced delay costs totaling \$45.5 million. On the other hand, continued expansion by using the series of alternatives that build a duplicate runway system next to the null system would seem to be a poor plan. Although delay would be dropped to extremely low levels, the land cost is prohibitive and would nearly double the total 20-year cost of operation. The dual runway would need no additional land for construction, but these alternatives would require a large outlay. Note further that the land and construction costs do not include glide path clearance costs, or the necessary cost of redesigning the terminal and parking facilities.

The stability of these results is very high. The same results were achieved by both 10-year analyses as well as the 20-year analysis. This indicates that such an expansion has been worthy of consideration for some time, and should continue to be attractive. In other words, a marked reduction in total operating cost would be realized if the dual runway had been implemented at any time since 1964. The earlier the construction had taken place, the greater the overall savings would have been for the full planning period.

Subjecting these results to the sensitivity analysis produced no change in the relative ranking of preference among the alternatives. Naturally, the actual dollar costs involved for all alternatives varied as parameter values were changed, yet the dual runway option remained a clear-cut best choice. Several factors help to account for the obvious superiority of this alternative. Most important of these is the decision by MWAS to set an upper limit on the number of operations handled at Washington National Airport. This ceiling has been set at 342,700 operations/year. In terms of demand estimates, this means a steady demand, not a growing one, throughout most of the second decade of the study. Therefore, there is little necessity for planning for major expansion of the airport, and the results from the earlier years indicate that the dual runway would be beneficial even at a lower level of operation. This, in combination with the very high land cost involved with the expansion series of configurations, gives a competitive edge to the lower cost, limited-growth alternative that the dual runway configuration represents. It is a question of building one runway on the current land or buying new land and building only one runway on the new land. The dual runway is less expensive and is effective enough for the policy-limited demand on National Airport facilities.

Another policy already in effect in Washington, D.C., makes the dual runway more appealing. This policy directs all operations involving large superjets to Dulles Airport, thereby allowing the close-distance parallel runway scheme to be more effective in practice at Washington National.

ANALYSIS OF DULLES INTERNATIONAL AIRPORT

An analysis framework with 3 planning periods, identical in form to that for Washington National Airport, was applied to Dulles International Airport. In this case, though, the current configuration was not designated as the null alternative. Examination of the level of operations that Dulles Airport has had to handle showed them to be well below the practical capacity of the currently existing configuration.

Because of the low use of Dulles Airport runways, it was decided to use only a portion of the existing layout as the null configuration. The 2 near, intersecting runways were selected. Dulles Airport was designed and built on an extremely large tract of land partly acquired with future expansion in mind but mainly bought for purposes of a noise buffer and to control commercial development in the near vicinity of the airport. It was assumed, therefore, that all of the land that was actually acquired would also have been acquired had only the hypothetical 2-runway configuration been built originally. This expanse of available land also led to the assumption that no land acquisition would be needed to add the fourth runway used in the design of the alternatives.

The 3 alternatives are shown in Figure 3. The physical costs are given in Table 5. The second alternative is the actual current configuration. Table 6 gives the data for delay and operation calculations that have been estimated for these Dulles Airport alternatives.

The 3 alternatives examined develop directly from the original design of the airport, which left a definite pattern to follow in planning future expansion. Considering the assumptions previously made here that lead to a constant land cost independent of the number of runways, one might expect that the planning situation at Dulles Airport would lean heavily toward favoring expansion. There are only the increased maintenance costs to offset the benefits of delay reduction, and these benefits have been shown to be considerable at times.

In the Dulles Airport case, though, there is a more immediate factor involved that prevents the bias toward expansion from taking effect. This is simply that, because of the historically low use of Dulles facilities, the delays are already minimal. Although the costs of expansion are low, any improvement in service would be marginal enough not to justify the expansion.

The studies using all 3 planning periods yielded the same results. The best choice economically proved to be the hypothetical null case with only 2 runways. The 3-runway existing configuration was roughly 12 percent more costly overall, and the 4-runway expansion alternative was about equally more expensive compared with the 3-runway scheme. Table 7 gives this well-defined cost separation over the entire 20-year planning period. The modification factors for the data in Table 7 are as follows:

1. Interest rate of 8 percent,
2. Operations growth of 0 percent,
3. Land value growth of 26 percent,
4. Construction factor of 1.00, and
5. Salvage factor of 1.00.

For the null alternative, the combined aircraft and passenger delay costs are roughly equal to the maintenance cost; for the larger alternatives, maintenance costs climb well above delay costs. Although this is a strong indication of overbuilding, it should be recalled that the analysis does not include an evaluation of other planning factors that went into the Dulles design. It considers only runway-configuration-related costs. Presumably, what was gained in the actual design of Dulles offset the increased operation cost.

As with the Washington National Airport analysis, the stability of the solution is high. Large variations in the values of several variable factors would be necessary to alter the ranking results of the program. From an economic viewpoint, there is strong indication that the third runway is not required, and that no further expansion beyond the current 3 runways should be necessary at Dulles International for many years to come.

MULTIAIRPORT CONSIDERATIONS

In a growing number of situations, a number of airport facilities are clustered to serve a large city or, more likely, an entire region. In this context, planning each facility independently of the others or using them in this way is not necessarily the best methodology. In Washington, D.C., MWAS directs all international flights and all jumbo jets to Dulles International Airport. Through demand manipulations such as this, the operations at any individual airport can be greatly altered. The question naturally arises about how the demand should be allocated for best results overall; therefore, multiairport planning considerations become necessary without choice.

The Washington, D.C., example seems ideally suited for such an investigation based on the results of analysis of the 2 individual airports. Demand is already being manipulated between Dulles and National; it would be desirable to study the implications of this process in

Figure 1. Functional organization of computer program.

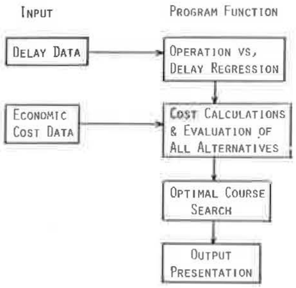

Table 1. Operation levels of Washington National and Dulles International airports.

Type of Data	Year	National Airport	Dulles Airport	Type of Data	Year	National Airport	Dulles Airport
Historical	1964	290 640	131 726	Projected	1974	330 400	189 900
	1965	308 972	156 488		1975	335 400	194 700
	1966	319 711	172 930		1976	340 600	199 800
	1967	318 072	193 688		1977	342 700	206 400
	1968	341 399	220 818		1978	342 700	216 300
	1969	341 500	217 114		1979	342 700	226 200
	1970	333 548	204 910		1980	342 700	237 300
	1971	317 731	190 237		1981	342 700	247 900
	1972	321 300	190 800		1982	342 700	261 200
	1973	325 300	185 500		1983	342 700	277 400

Figure 2. Alternative runway configurations for Washington National Airport.

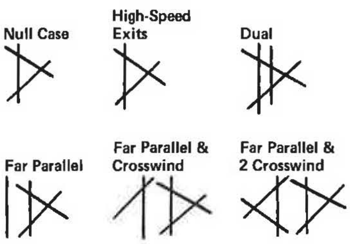

Table 2. Cost components for alternative runway configurations for Washington National Airport.

Runway Configuration	Costs (millions of $) Additional Land	Construction for Addition	Duplicative Setup	Annual Maintenance
Null case	231.710	0	0	1.538
High-speed exits	0	2.927	0	1.698
Dual	0	3.550	0.355	2.268
Far parallel	343.46	15.578	1.558	2.351
Far parallel and crosswind	0	9.494	0.949	2.847
Far parallel and 2 crosswind	0	9.494	0.949	3.942

Table 3. Delay versus operation data for alternative runway configurations for Washington National Airport.

Operations	Delay (h) Null Case	High-Speed Exits	Dual Runway	Far Parallel	Far Parallel and Crosswind	Far Parallel and 2 Crosswind
290 000	7 400 000	7 250 000	4 166 000	2 456 000	2 280 000	1 981 000
300 000	9 028 000	8 839 000	5 315 000	2 592 000	2 528 000	2 128 000
310 000	10 791 000	10 632 000	6 464 000	2 826 000	2 745 000	2 286 000
320 000	13 358 000	13 018 000	7 815 000	3 082 000	2 947 000	2 453 000
330 000	15 947 000	15 815 000	9 471 000	3 393 000	3 222 000	2 631 000
340 000	18 583 000	18 226 000	10 846 000	3 681 000	3 476 000	2 814 000
350 000	21 695 000	21 254 000	12 451 000	4 058 000	3 804 000	2 995 000

Table 4. Twenty-year analysis results for Washington National Airport.

Alternative	Costs (millions of $) Passenger Delay	Aircraft Delay	Maintenance	Construction	Land	Total
Null case	37.075[a]	73.261	15.103	0.000	214.545	339.984
High-speed exit runway	36.447	72.020	16.671	2.710	214.545	342.393
Dual runway with high-speed runway[b]	21.737	42.954	22.271	5.673	214.545	307.180

[a]Present worth. [b]Optimal runway configuration.

Figure 3. Alternative runway configurations for Dulles International Airport.

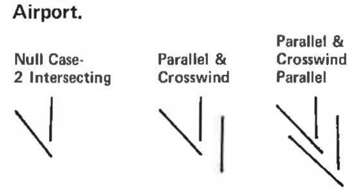

Table 5. Cost components for alternative runway configurations for Dulles International Airport.

Runway Configuration	Costs (millions of $) Additional Land	Construction for Addition	Duplicative Setup	Annual Maintenance
Null case, 2 intersecting	57.830	14.490	0	1.096
Parallel and crosswind	0	8.280	2.070	1.683
Parallel and crosswind parallel	0	8.280	2.070	2.193

detail. Also 2 prominent points emerge from the individual studies. Washington National Airport is overcrowded and expensive to operate and would be even if the dual runway were added. Dulles International is underused and would be even if only 2 of the 3 current runways had been built.

The complementarity of these results is obvious. Attention was focused on the consequences of diverting air traffic from National to Dulles by using the mechanism of a lowered operations level ceiling at National Airport. Data for the 1974-1983 planning period were used for this analysis to show what could be done now. Figure 4 shows the current projection for division of operations between the 2 Washington airports. The annual number of operations at National levels off at the estimated value for 1977, which is 42,700 operations. Analyses were run that shifted enough flights to Dulles International in subsequent years to reduce the National Airport demand load to 90, 80, and 70 percent of the original projected level. If the reduction of delay at National is significantly larger than the additional delay at Dulles, then a net benefit should result.

The results bear out the expectations of overall reduced costs. If we use the current 3-runway configurations, the total cost (excluding land cost) in present worth terms for 1974 drops from the original $126.31 million to $91.79 million for an operation cutback to 90 percent and $77.66 million for an operation cutback to 80 percent. If no additional runways are built, then there is a potential of saving about $35 million to $50 million over the next 10 years.

Adding the dual runway at National Airport lowers the original cost total (excluding land cost) of $98.54 million to $79.47 million with a 10 percent demand shift and to $65.46 million with a 20 percent shift. Again, large savings, even in discounted terms of present worth, are possible. The results for a 30 percent demand transfer from National gave spurious delay figures because of the extremely low delay levels.

It should be reemphasized that these savings accrue to aircraft operators and passengers, not to the airport operators themselves, who must fund the runway construction at National. Benefits to be derived by the operators directly would include only such things as reduced operational problems and so on, although the service provided would appear to improve dramatically.

The aircraft operators clearly benefit from reduced delay. Aircraft operating cost totals are given in Table 8

Table 6. Delay versus operation data for alternative runway configurations for Dulles International Airport.

	Delay (h)		
Operations	Null Case	Parallel and Crosswind	Parallel and Crosswind Parallel
75 000	187 000	105 000	104 000
100 000	337 000	189 000	182 000
150 000	787 000	432 000	424 000
200 000	1 512 000	788 000	761 000
250 000	2 742 000	1 281 000	1 213 000
300 000	5 845 000	2 019 000	1 810 000
350 000	12 839 000	3 080 000	2 723 000
400 000	24 349 000	4 667 000	3 646 000
450 000	46 318 000	6 885 000	5 057 000
500 000	82 657 000	9 734 000	7 010 000

Table 7. Twenty-year analysis results for Dulles International Airport.

	Costs (millions of $)					
Alternative	Passenger Delay	Aircraft Delay	Maintenance	Construction	Land	Total
Null case[b]	3.776[a]	6.468	10.765	0.000	53.550	74.559
Parallel and crosswind runway	1.977	3.386	16.524	7.667	53.550	83.104
Parallel and crosswind parallel runway	1.927	3.300	21.531	13.417	53.550	93.725

[a]Present worth. [b]Optimal runway configuration.

Figure 4. Demand split of the 2 study airports.

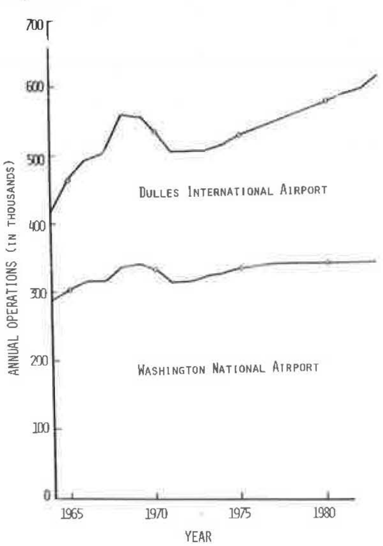

Table 8. Combined airport operation costs, 1974-1983.

	Costs (millions of $)		
Configurations	Passenger Delay	Aircraft Delay	Total Excluding Land
Current			
Current demand split	35.757	64.271	126.310
10% demand split	21.209	41.300	91.791
20% demand split	16.549	31.888	77.656
Current National and 2-runway Dulles			
Current demand split	34.461	67.190	119.331
10% demand split	24.366	46.708	88.774
20% demand split	22.546	42.160	82.386
Dual National and Current Dulles			
Current demand split	19.872	38.810	98.536
10% demand split	13.517	26.101	79.472
20% demand split	8.898	16.770	65.459

for the courses of action just discussed. Savings are substantial for this segment of the airport population. Passengers, on the other hand, may find it hard to accept the notion that landing at Dulles is more convenient than landing at National, which is closer to central Washington. After assuming the number of trips to the center of the District of Columbia made from these airports, one can calculate the additional costs of these transfer passengers. Each 10 percent shift represents roughly 1 million passengers. For that subgroup of passengers who have Washington as a final destination, the additional costs caused by landing at distant Dulles must be considered to fully investigate the economics involved. These costs include the added time necessary to reach downtown Washington (or whatever destination) and the added fare involved for such a trip compared with a similar trip from National. The increased number of passengers making this trip from Dulles could warrant consideration of a provision of mass transit. That is,

$$S = T_o - T_n + P(G) \quad (1)$$

where

S = potential savings,
T_o = original total operation cost,
T_n = new total operation cost,
P = number of passengers transferred, and
G = ground transport cost (including delay) per passenger.

Obviously, such a broad scope is beyond the problem outlined for this research, but it demonstrates how the time-staging decision model for runway configurations can be used in conjunction with a larger scale analysis by yielding cost information for the configuration subsystem.

CONCLUSIONS

The suggested approach to the configuration expansion planning is a computerized analysis that is capable of greatly benefiting the planning and design phases of airport runway operation. The program is designed to provide to those involved with improvement decisions and policies the body of tangible information needed to carefully evaluate the consequences of potential configurations to be applied to future air travel needs. An effort has been made to keep all aspects of the developed methodology, including data requirements and analytic sophistication, at a reasonable level to facilitate use in actual practice. The solution method is capable of handling most planning cases that may arise and can be adapted to handle other cases beyond this majority through careful input technique and problem structuring.

Several conclusions can be drawn based on the result of this study.

1. The economic costs (land cost, construction cost, maintenance cost, delay costs, and salvage value) reflect the major component costs (to airport operators and users) that are directly related to runway configuration.
2. The data requirements of the economic analysis are not unreasonable for a long-range planning effort. The data items are ones that should rightfully be considered in a comprehensive plan, yet they are currently difficult to obtain.
3. Development of the computer program as a planning aid with built-in comparative analysis and sensitivity analysis has proved much more valuable than a program that only mathematically optimizes.
4. For Washington National Airport, the addition of a dual fourth runway is indicated as desirable at any time between 1964 and 1983, the bounds of the planning period examined. Addition of high-speed exits alone was shown to be uneconomical in terms of reducing delay.
5. For Dulles International Airport, the analysis results indicate that 2, rather than the current 3, runways are capable of efficiently accommodating projected demands through 1983. This is true even though no additional land cost was involved for adding the third runway.
6. Preliminary investigations of the combined airport costs reveal potentially sizable savings through control of demand split between the 2 Washington, D.C., airports. These cost reductions, which would aid the aircraft operators and passengers, would occur both with and without addition of the dual runway at National Airport.
7. Throughout the case example runs, the stability of the solutions was high, which indicates clear-cut distinctions of all alternatives in terms of economic costs and operating characteristics.

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