Arrival/Departure Capacity Tradeoff Optimization: a Case Study at the St. Louis Lambert International Airport (STL)

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Abstract

The busiest European and US airports are still a major bottleneck in the air transportation network. Optimizing utilization of existing airport capacity during periods of congestion, to maximize the airport throughput and minimize delays, is a challenging task. It is important for both strategic (several hours into the future) traffic flow management (TFM) and tactical air traffic control (ATC). One of the more effective approaches to optimizing the existing airport capacity is dynamic allocation of arrival and departure capacities by trading off between them at airports for which this is an option. The theoretical aspects of the problem are addressed in [2] – [4]. A novel automated decision support tool, arrival/departure tradeoff optimization tool, which will assist the traffic flow management specialists select the best arrival and departure strategies is being developed at the Volpe National Transportation Systems Center (Volpe Center) within the scope of the Federal Aviation Administration (FAA) Collaborative Decision Making (CDM) program. The prototype tool was tested and evaluated in a case study at the St. Louis Lambert International Airport (STL). The case study is the first on-site experiment in which the optimization technique and decision support tool were tested in a real time situation, allowing for the strategic, coordinated management of airport arrival and departure capacity and arrival and departure traffic. This paper presents the results of the case study.

Introduction

The busiest European and US airports are still a major bottleneck in the air transportation network. The continuously growing gap between air traffic demand and limited airport capacity causes severe congestion problems at many major airports. Lack of airport capacity to accommodate the traffic demand leads to increase of delays, disruption of airline operations and inconvenience for passengers. Nationwide annual losses due to air traffic delays are estimated in billions of dollars.

The FAA is pursuing various strategies to alleviate congestion and reduce traffic delays such as building new airports, physical expansion of existing runway systems, application of new technologies to increase airport capacity, demand management initiatives to limit traffic demand at capacity-constrained airports and operational measures to improve utilization of existing airport capacity [1]. Among the operational measures, a potentially effective one is the strategic management of arrival and departure operations by optimal, dynamic allocation of arrival and departure capacities at the airports where these two capacity components can be traded one for another [2] – [4]. Almost all major, capacity-constrained airports have runway configurations whose Airport Arrival Rates (AAR), or arrival capacity, and Airport Departure Rates (ADR), or departure capacity, are interconnected by a tradeoff relationship; i.e., within some limits arrival capacity can be increased at the expense of decreasing departure capacity and vice versa.

In practice, the air traffic managers know the range of arrival/departure capacity tradeoff available for each runway configuration and use the tradeoff for strategic planning of arrival and departure traffic during periods of congestion. Extensive statistical analysis of historical ETMS (the FAA Enhanced Traffic Management System) data on actual arrivals and departures for major US airports, as well as recent benchmarking of 31 US airports (see [5]), confirmed the tradeoff phenomenon. Air traffic management specialists may vary airport arrival and departure operational limits during the periods of congestion to better serve the traffic demand. However, currently they do it mostly intuitively not having any automated decision support to determine the best tradeoff strategies for allocation of airport arrival and departure rates. Sometimes an experienced specialist can find the best solutions but, in more complex traffic situations, he/she may miss the best ones. This points to the benefits of developing a decision support tool to help the air traffic management specialists determine the best airport arrival and departure rates and the best TFM strategies at airports on a regular basis. The Volpe Center is developing such a tool within the scope of the FAA Collaborative Decision Making (CDM) Program. The tool is called Arrival/Departure Tradeoff Optimization Tool. The basic mathematical formulation of the arrival/departure tradeoff optimization problem for strategic traffic flow management at airports is given in [2].

The FAA requested the Volpe Center to conduct a case study on the use of the tool at a specific airport. The case study would explore how the air traffic managers at the FAA Terminal Radar Approach Control (TRACON) facilities and Air Traffic Control (ATC) Towers could use the tool for strategic TFM, and evaluate potential benefits for improving the airport arrival and departure operations. St. Louis Lambert International Airport (STL) was chosen for the first case study, which was conducted during March – October 2000. It was actually the first practical experiment when the optimization technique and decision support tool was tested on site for improvement of airport capacity utilization and TFM strategic decision-making.

The paper describes the results of the case study. The study was a collaborative effort between the Volpe Center, the FAA STL facility (TRACON and ATC Tower) and TWA air traffic management staff. (TWA was a dominant airline user of STL at that time).

During the study, the FAA STL and airline specialists tested the tool in real time airport operations and gave valuable suggestions that allowed for substantial improvements of the tool's functionalities.

The study was designed to address several issues. First, the realistic arrival/departure capacity curves for all STL runway configurations had to be determined and confirmed by local TFM specialists. Second, the feasibility of the arrival/departure tradeoff optimization concept, based on 15-minute demand and capacity counts, had to be tested. Finally, most importantly, the study needed to determine how local TFM specialists would receive the optimization idea and use the tool to support their strategic TFM decision-making.

The paper is organized as follows. Section 1 describes the overall design of the case study. Specifics of the STL airport capacity curves are discussed in Section 2. A brief description of the optimization model and the basic features of the tool are given in Section 3. Section 4 describes numerical experiments and presents some examples that illustrate potential benefits of using the optimization tool as well as specifics of optimal solutions for STL. A proposed operational concept of using the tool is presented in Section 5. The results of the case study are summarized in the Conclusion. The airport arrival/departure capacity curves for all active STL runway configurations are presented in Appendix.

1. Overall Design of the Study

An initial step of the study was to introduce a full set of the airport arrival/departure capacity curves for all active runway configurations at STL and various operational weather categories. The curves would determine the tradeoff areas for arrival and departure capacities for each runway configuration and weather condition. The FAA STL traffic management specialists provided the set of capacity curves. The fact that the curves were given by the local TFM specialists and potential users of the tool was very important because they provided realistic operational limits of the airport under various conditions based on their own experience. The latter would make the specialists and other users more confident in the feasibility of optimal solutions generated by the tool.

The arrival/departure tradeoff optimization tool is based on 15-minute counts for both traffic demand and airport capacity. The full set of STL 15-minute capacity curves is presented in Appendix.

The study was conducted in two directions:

1. Comparison of TFM strategies suggested by the STL TFM specialists without using the optimization tool with the optimal strategies generated by the tool on the same demand data and airport capacity scenario. All participants of the study then jointly analyzed the results. This made it possible to evaluate potential benefits of the arrival/departure tradeoff optimization for improving utilization of airport capacity during periods of congestion.
2. On-line testing and "playing" with the tool by the traffic management specialists (both FAA and TWA) for strategic planning of the air traffic and airport arrival and departure rates using the real-time ETMS arrival and departure demand predictions. During these exercises, the participants became familiar with the tool, performed "what if" analyses of various airport capacity scenarios and arrival/departure strategies to best solve the predicted congestion problems, and evaluated potential benefits of using the tool for the Collaborative Decision-Making. The traffic management specialists made some valuable suggestions to improve the tool.

2. Specifics of Arrival/Departure Capacity Curves for Runway Configurations at STL

The STL airport has three active runways: two parallel runways 30L (12R) and 30R (12L), which are crossed by the third runway 24 (06). There is a forth runway 31 (13) that is not currently used.

Here is an example of conventional notation for runway configurations. The runway configuration A 30RL, 24 / D 30LR uses three runways 30R, 30L and 24 for arrivals and two runways 30R and 30L for departures.

The 15-minute arrival/departure capacity curve of this configuration for VIS (Visual Approach) operational category is shown in Figure 1.

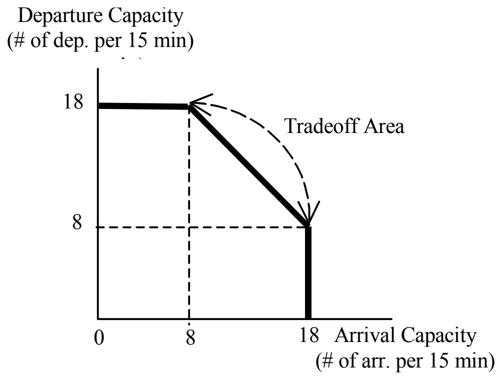

Figure 1. Arrival/Departure Capacity Curve of Runway Configuration A 30RL, 24 / D 30RL, VIS

According to Figure 1, the airport operational resources of this runway configuration are flexible within a wide-range tradeoff area. The area comprises eleven integer arrival/departure capacity pairs (see Table 1) each of which can be realized at any 15-minute interval of the time period when the runway configuration is used. This gives traffic management specialists many options for allocation of airport arrival and departure capacity to manage traffic demand during the peak hours.

Table 1. Arrival/Departure Capacity Pairs within the Tradeoff Area of Figure 1

Airport Capacity per 15 minutes	
Arrival	Depart.
8	18
9	17
10	16
11	15
12	14
13	13
14	12
15	11
16	10
17	9
18	8

It is important to notice that the tradeoff area of the capacity curve in Figure 1 consists of a single line with the slope of 45°. This means that the sum of the arrival and departure capacities within the tradeoff area is constant. According to Table 1, the runway configuration A 30RL, 24 / D 30LR has a constant total (arrival plus departure) capacity of 26 flights per 15 minutes with various allocations of these two capacity components.

Constant total capacity is a common property of all of the runway configurations at STL. However, the tradeoff areas, as well as total capacities for different runway configurations and weather conditions, may be different. Hence, each runway configuration at STL has an arrival/departure capacity curve with a tradeoff area represented by a single line between two vertices. Therefore, in the remainder of this paper, the arrival/departure tradeoff area will be denoted by a range between two extreme arrival/departure capacity pairs, or between two vertices of the curve: (minimum arrival capacity/ maximum departure capacity – maximum arrival capacity/minimum departure capacity). For instance, the tradeoff area of the curve in Figure 1 is (8/18 – 18/8). The rest of capacity pairs between these two extremes can be easily interpolated given the total capacity value of 26 (see Table 1).

The arrival/departure capacity curves (their tradeoff areas) for the full set of STL runway configurations are presented in Appendix.

3. Optimization Model and Basic Features of the Tool.

The first mathematical model for the optimal allocation (tradeoff) of airport arrival and departure capacities for strategic traffic flow management was formulated in [2]. The model was used in the arrival/departure tradeoff optimization tool and was realized by a discrete combinatorial optimization algorithm.

The basic idea of the optimization approach is as follows. For a specific period of time at an airport, predicted traffic demand for both arrivals and departures at each 15-minute interval is determined. Predicted weather conditions and schedule of runway configurations with the corresponding 15-minute capacity curves during the period are also determined. Both the traffic demand and the airport capacity scenario (sequence of airport capacity curves) constitute input data to the optimization program. For each capacity curve, a set of integer arrival capacity/departure capacity pairs in a tradeoff area is calculated to introduce a domain of optimization variables.

The optimization algorithm determines the best arrival and departure rates at each 15-minute interval that minimize a weighted sum of cumulative arrival and departure queues[1]:

Minimize {alpha * cumulative_arr_queue + (1 – alpha) * cumulative_dep_queue},

where alpha is a parameter between 0 and 1 that can be assigned by a traffic management specialist to get solutions more favorable to arrivals (alpha is greater than 0.5) or to departures (alpha is less than 0.5). Alpha = 0.5 corresponds to the minimum sum of the arrival and departure cumulative queues. Alpha is called the "arrival priority" parameter.

[1] The arrival and departure queues equal the number of flights waiting to land and takeoff at the end of each 15-minute interval, respectively. The cumulative queues are the sum of the queues for each 15-minute interval over the time period of interest.

As no other information on traffic demand than 15-minute counts is being used, the cumulative queue can be used for a rough estimation of the total delay for all flights in the demand. In particular, if there is no outstanding queue left at the end of a time period of interest, the cumulative queue at the end of a time period is equal to the total aircraft flight delay expressed in the number of 15-minute blocks [3]. The total delay time in minutes is equal to the cumulative queue multiplied by 15-minutes. Hence, the above criterion provides the optimal solution that also minimizes a weighted sum of total arrival and departure delay.

The optimal solution includes arrival and departure rates and traffic flow compatible with the rates at each 15-minute interval as well as the queues at the end of each 15-minute interval.

Because all runway configurations at STL have constant total (arrival plus departure) capacity within their arrival/departure tradeoff areas, there is a possibility of obtaining multiple optimal solutions for the periods of congestion. For instance, for alpha = 0.5, each solution in this case provides the same minimum total (arrival plus departure) cumulative queue but with different allocation of arrival and departure capacities and queues at some 15-minute intervals.

For more detail on mathematical formulation of the optimization problem see [2] – [4].

The arrival/departure tradeoff optimization tool is a web-based application. The main page of the tool (see Figure 2) allows the user to enter initial settings for determining a traffic flow management strategy at the selected airport. Currently the tool is connected through ETMS to the thirty major US airports shown in Figure 2. The airport ID’s in the figure are given in accordance with the ICAO standards. After the airport has been selected, the user sets the time period of interest, the schedule of runway configurations during the period, the weather-related operational categories for each configuration, and the value of arrival priority parameter alpha.

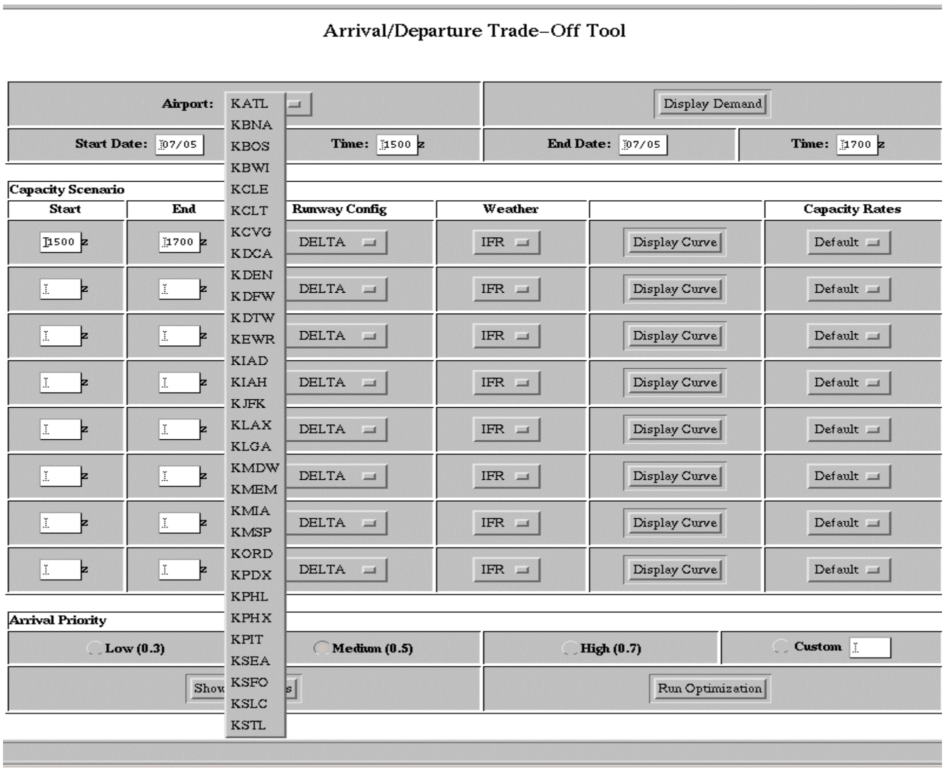

Figure 2 The Main Page of the Arrival/Departure Tradeoff Optimization Tool

The arrival/departure capacity curves for all runway configurations and weather conditions are stored in the files and are used as the default capacity data. The tool also allows the user to edit capacity curves and enter the rates that differ from the default ones.

After selecting or setting all of the required parameters, the user retrieves from ETMS the latest predictions for arrival and departure demand at each 15-minute interval of the time period of interest. He/she can review the demand to check whether there are congested 15-minute intervals when the predicted demand exceeds capacity. This check can be performed automatically by the tool.

The “Run Optimization” function triggers the optimization algorithm and displays the optimal solution(s). The solutions are displayed by tables and bar charts. In the case of multiple optimal solutions, all solutions can be viewed. Each solution is accompanied by a summary, which gives the cumulative arrival and departure queues over a time period of interest, the total arrival and departure delays, and the average arrival and departure delays per flight.

The tool allows for updating predictions for traffic demand, changing the airport capacity scenario (if necessary), and updating optimal solutions.

4. Numerical Experiments

All numerical experiments during the case study were performed on the predicted arrival and departure demand data for the runway configuration A 30RL, 24 / D 30RL under VIS operational conditions. The arrival/departure capacity curve for this configuration and the set of arrival/departure capacity pairs in the tradeoff area are presented in Table 1 and Figure 1, respectively.

The most extensive numerical experiments were conducted on the data for July 20, 21, August 1, 9, 14, 15, and 16 of the year 2000. Some results of the experiments are presented and discussed in this section. The optimal strategies shown in this section are obtained for alpha = 0.5 in the optimization criterion, and thus minimize the sum of the arrival and departure cumulative queues as well as the total arrival plus departure aircraft flight delay.

The experiments were organized as follows. For each predicted traffic demand and airport capacity scenario, the STL traffic management specialists gave their expert version of the strategy to resolve a congestion problem. After that, the arrival/departure optimization tool calculated the optimal TFM strategies for the same data. To estimate potential benefits of the optimization tool, the cumulative queues and total delays resulting from the strategy proposed by the STL TFM specialists and the optimal strategy were then compared.

The tool generated optimal TFM strategies that were better than or comparable to what the STL specialists suggested in terms of cumulative queues and delays. In the cases when the optimal solutions were noticeably better, the reduction in the total cumulative queues and delays were up to 31%.

As previously mentioned, there is a very important property of the airport capacity curves for all runway configurations of the STL airport that affects the properties of optimal solutions. Namely, the sum of arrival and departure capacities within the tradeoff are is constant and the constant value may vary with runway configuration (see Table A in the Appendix). As a result, in the case of congestion at the airport, there is a possibility for obtaining several optimal strategies that minimize the sum of cumulative arrival and departure queues, or minimize the sum of total arrival and departure delays (with arrival priority parameter alpha equal 0.5 in the optimization criterion). Even in the cases when the strategies suggested by the STL TFM specialists satisfied the optimality criterion, the specialists provided only one solution for each case while the optimization program found multiple optimal solutions. This is important because multiple optimal solutions offer the TFM specialists some options for selecting the best strategy keeping in mind factors beyond the optimization model. Moreover, in the Collaborative Decision Making environment, the airlines input may help the TFM specialists to select the optimal strategy from the set of options that satisfy both traffic flow management and airlines' priorities.

For the sake of conciseness, only two examples from the series of experiments conducted during the study will be presented below. These examples illustrate the typical effects of the arrival/departure tradeoff optimization at the STL airport.

4. 1 Example 1: July 21, 2000, 1745 - 1900

Table 2 shows initial traffic demand predicted for 1745 – 1900 period, and the TFM strategy suggested by the STL traffic management specialists.

Table 2. TFM Strategy Proposed by the STL Specialists, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	13	13	13	13	3	3
1830 - 1845	7	19	10	16	10	16	0	6
1845 - 1900	4	13	8	18	4	18	0	1
TOTAL	50	64			50	63	3	10

This strategy provides the sum of cumulative arrival and departure queues equal to 13 flights (3 arrival and 10 departure flights) with the total aircraft flight delay of 195 minutes (45 minutes of arrival and 150 minutes of departure delay) and average delay per arrival and departure flight of 0.9 minutes and 2.3 min, respectively. The original departure demand was not completely satisfied at the end of the time period, leaving one departure flight in the queue after 1900. Arrival demand was satisfied completely within the time period.

The arrival/departure tradeoff optimization tool calculated the optimal TFM strategies for the initial traffic demand using the set of arrival and departure capacity pairs shown in Table 1. The tool found 15 optimal solutions with the same minimum sum of arrival and departure cumulative queues equal to 12 flights with the total aircraft flight delay of 180 minutes. Some of the optimal solutions are shown in Tables 3 – 7. The optimal solutions differ by different allocation of arrival and departure capacities at some 15-minute intervals as well as by different allocation of arrival and departure components within the sum of cumulative queues and the total delay. The optimal solution is 8% better than the one proposed by the STL specialists in terms of the sum of cumulative arrival and departure queues and the total delay. Moreover, the optimal strategy increased the airport throughput so that, in contrast with the strategy of Table 2, both arrival and departure initial demands were completely served within the time period from 1745 to 1900 with no queue at the end of the time period.

Table 3 represents the optimal strategy that is most favorable to arrivals.

Table 3. Optimal TFM Strategy, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	14	12	14	12	2	4
1830 - 1845	7	19	8	18	8	18	1	5
1845 - 1900	4	13	8	18	5	18	0	0
TOTAL	50	64			50	64	3	9

The strategy provides 3 arrival and 9 departure flights in cumulative queues, 45 minutes of total arrival delay and 135 minutes of total departure delay with 0.9 minutes and 2.1 minutes of average arrival and departure delay per flight, respectively.

Tables 4 and 5 represent two optimal strategies that provide a better balance between arrivals and departures. One can see the difference between these two solutions with similar allocation of cumulative arrival and departure queues and delays. Both strategies provide 75 minutes of total arrival delay and 105 minutes of total departure delay with 1.5 minutes and 1.6 minutes of average arrival and departure delay per flight, respectively.

Table 4. Optimal TFM Strategy, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	13	13	13	13	3	3
1830 - 1845	7	19	8	18	8	18	2	4
1845 - 1900	4	13	9	17	6	17	0	0
TOTAL	50	64			50	64	5	7

Table 5. Optimal TFM Strategy, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	12	14	12	14	4	2
1830 - 1845	7	19	10	16	10	16	1	5
1845 - 1900	4	13	8	18	5	18	0	0
TOTAL	50	64			50	64	5	7

The difference between these two strategies is in allocation of arrival and departure capacities in three consecutive 15-minute intervals starting from 1815 that resulted in different allocation of arrival and departure flows and queues during these intervals. Which of these two strategies would be more attractive to traffic management specialists and airlines representatives depends on criteria beyond those considered in the optimization model. For instance, they may prefer the strategy that results in minimizing the size of the largest queue in any 15-minute interval. In this case, the strategy in Table 4 would be preferable because it provides a maximum queue (arrival or departure) of 4 compared to a maximum queue of 5 in Table 5. In this particular example, it turns out that the strategy depicted in Table 4 results in minimizing the size of both the largest arrival and departure queues.

Table 6 represents the optimal strategy, which is most favorable to departures.

Table 6. Optimal TFM Strategy, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	10	16	10	16	6	0
1830 - 1845	7	19	8	18	8	18	5	1
1845 - 1900	4	13	9	17	9	14	0	0
TOTAL	50	64			50	64	11	1

The strategy provides 11 arrival and 1departure flights in cumulative queues, 165 minutes of total arrival delay and 15 minutes of total departure delay with 3.3 and 0.2 minutes of average arrival and departure delay per flight, respectively.

The following discussion illustrates the specifics of optimal solutions and how the STL TFM specialists and the airport users could benefit from using the arrival/departure tradeoff optimization tool.

Let's first analyze the strategy proposed by the STL specialists. According to Table 2, the STL TFM specialists have chosen AAR = 10 and ADR = 16 for the 1830 –1845 interval. At first glance, their suggestion to use these rates looks attractive because with an arrival rate of 10 all arrival flights would be served, leaving no arrival queue by 1845. However, with the departure rate of 16 flights, the departure queue at the end of the interval would be equal to 6. After adding the queues to the initial demand for the next 15-minute interval, the amended demand for the 1845 – 1900 interval would be 4 arrival and 19 departure flights. There is enough arrival capacity to serve all four arrival flights, but it is not possible to serve all 19 departure flights during the 15-minute interval because maximum departure capacity available is only 18. Therefore, the best arrival/ departure capacity pair for the 1845 – 1900 interval (AAR = 8 and ADR = 18) still leaves one departure flight in the queue at the end of the time period. Thus, selecting these non-optimal rates for one 15-minute interval (1830 - 1845) prohibits the TFM specialists from correcting the situation during the next 15-minute interval.

Table 4 shows an optimal strategy that retains the STL traffic management specialists' suggestions for the first three 15-minute intervals and offers a better capacity allocation at the subsequent intervals. Table 7 shows an alternative optimal solution, which also retains the specialists' suggestions for the first three 15-minute intervals. As previously indicated, the solution in Table 4 is one that is relatively balanced between arrivals and departures, with an average arrival and departure delay per flight of 1.5 and 1.6 minutes, respectively. The optimal strategy shown in Table 7 slightly favors arrivals, with the average arrival and departure delay per flight of 1.2 and 1.9 minutes.

Table 7. Optimal TFM Strategy, 7/21/00, 1745 - 1900

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1745 - 1800	10	5	13	13	10	5	0	0
1800 - 1815	13	11	13	13	13	11	0	0
1815 - 1830	16	16	13	13	13	13	3	3
1830 - 1845	7	19	9	17	9	17	1	5
1845 - 1900	4	13	8	18	5	18	0	0
TOTAL	50	64			50	64	4	8

4.2 Example 2: August 16, 2000, 1500 - 1615

In this example, the optimal solutions provided more significant improvement of the TFM strategy proposed by the STL TFM specialists than in the previous one. Table 8 shows the initial traffic demand predicted for the 1500 – 1615 period on August 16, 2000, and the TFM strategy proposed by the STL TFM specialists.

Table 8. TFM Strategy proposed by the STL specialists, 8/16/00, 1500 - 1615

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1500 – 1515	9	14	13	13	9	13	0	1
1515 – 1530	17	13	13	13	13	13	4	1
1530 – 1545	16	11	16	10	16	10	4	2
1545 – 1600	10	10	13	13	13	12	1	0
1600 – 1615	4	6	13	13	5	6	0	0
TOTAL	56	54			56	54	9	4

This strategy results in the sum of cumulative arrival and departure queues equal to 13 flights (9 arrival and 4 departure flights) with the total aircraft flight delay of 195 minutes (135 minutes of arrival and 60 minutes of departure delay) and average arrival and departure delay per flight of 2.4 and 1.1 minutes, respectively. The original demand for both arrivals and departures was completely satisfied by the end of the time period. The strategy presented in Table 8 looks more favorable to departures.

The arrival/departure tradeoff optimization tool determined 27 optimal TFM strategies with the minimum sum of arrival and departure cumulative queues equal to 9 flights, corresponding to a total aircraft flight delay of 135 minutes. Some of optimum strategies are shown in Tables 9 – 11. The optimal strategies reduced the sum of cumulative arrival and departure queues and total delay by 31% relatively the strategy proposed by the STL specialists in Table 8. This is a strong indication that adoption one of these optimized strategies would have substantially improved utilization of airport capacity and increased the airport throughput.

Table 9. Optimal TFM Strategy, 8/16/00, 1500 - 1615

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1500 – 1515	9	14	12	14	9	14	0	0
1515 – 1530	17	13	17	9	17	9	0	4
1530 – 1545	16	11	16	10	16	10	0	5
1545 – 1600	10	10	10	16	10	15	0	0
1600 – 1615	4	6	13	13	4	6	0	0
TOTAL	56	54			56	54	0	9

The strategy shown in Table 9 is most favorable to arrivals. It provides no arrival delay and 135 minutes of total departure delay, with 0 and 2.5 minutes of average arrival and departure delay per flight, respectively.

Table 10. Optimal TFM Strategy, 8/16/00, 1500 - 1615

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1500 – 1515	9	14	12	14	9	14	0	0
1515 – 1530	17	13	15	11	15	11	2	2
1530 – 1545	16	11	15	11	15	11	3	2
1545 – 1600	10	10	13	13	13	12	0	0
1600 – 1615	4	6	13	13	4	6	0	0
TOTAL	56	54			56	54	5	4

The strategy shown in Table 10 is a balanced strategy. It provides 5 arrival and 4 departure flights in cumulative queues, 75 minutes of total arrival delay and 60 minutes of total departure delay, with 1.3 and 1.1 minutes of average arrival and departure delay per flight, respectively.

Table 11. Optimal TFM Strategy, 8/16/00, 1500 - 1615

Time	Initial Demand		Airport Capacity		Traffic Flow		Queue	
	arr	dep	arr	dep	arr	dep	arr	dep
1500 – 1515	9	14	12	14	9	14	0	0
1515 – 1530	17	13	13	13	13	13	4	0
1530 – 1545	16	11	15	11	15	11	5	0
1545 – 1600	10	10	15	11	15	10	0	0
1600 – 1615	4	6	13	13	4	6	0	0
TOTAL	56	54			56	54	9	0

The strategy shown in Table 11 is most favorable to departures, with 9 arrival and 0 departure flights in cumulative queues. It provides 135 minutes of total arrival delay and no departure delay, with 2.4 and 0 minutes of average arrival and departure delay per flight, respectively.

In the above examples, the tool generated multiple optimal solutions. The question is which of them should be selected for implementation. There is no single answer to this question. From the TFM specialist's point of view, each of the strategies can be realized. From the user's point of view, only some of the solutions (or only one of them) may be acceptable because of the specifics of airlines' schedules and operations (e.g., connecting flights, crew management, fleet maintenance, etc). In this case, collaborative interacting procedures between the traffic management specialists (at TRACON or ATC Tower) and users (airlines) should be established to select the best TFM strategies; i.e., ones that satisfy both the FAA traffic management specialists (operational resource providers) and airlines and other operational resource users. STL is a good airport for this kind of collaboration because there are only two major users there, TWA (now American Airlines) and SWA.

5. Proposed Operational Concept for Using the Tool

During the case study, special attention was paid to developing an operational concept for using the arrival/departure tradeoff optimization tool. As a result of discussions among all the parties involved in the study, the following operational concept was proposed.

The primary application of the tool is the strategic planning of arrival and departure traffic and airport capacity from 1 hour up to 23 hours into the future. In addition, the tool can be used for historical performance analysis of the airport for up to 11 hours back.

The tool would be used at both local (TRACONs and ATC Towers of major airports) and central (Air Route Traffic Control Centers (ARTCCs) and Air Traffic Control System Command Center (ATCSCC)) FAA facilities.

The TRACON and ATC Tower traffic management specialists use the tool to obtain optimal strategy for a specific airport over the time period of interest based on predicted traffic demand, airport runway configurations schedule, and predicted weather. Where applicable, the airport users (airlines) would participate in selection of the optimal strategies.

After the optimal strategy for the airport has been determined, the predicted airport arrival and departure rates (capacities) are submitted to the ARTCC and ATCSCC for review. Once the rates have been approved, they are introduced into the National Airspace System (NAS) and become available to the aviation community. In particular, the rates would be entered into the ETMS. During Ground Delay Programs, the rates would be used in the Flight Schedule Monitor (FSM) to determine arrival slots at the airport and calculate ground delay times using procedures and algorithms developed within the Collaborative Decision Making program [6].

6. Conclusion

The paper presented results of the case study on improving strategic traffic flow management for arrivals and departures at the STL airport. During the study, the arrival/departure tradeoff optimization techniques and a new decision support prototype tool were tested for the first time in real time operations at an airport. The tool aids the traffic flow management specialists in determining the best arrival and departure strategies at airports during the peak hours by optimal allocation of interdependent arrival and departure capacities. The case study demonstrated potential benefits of the tool for increasing the airport throughput and reducing traffic delays. This was accomplished by improving utilization of existing airport capacity through optimal, dynamic, coordinated management of arrival and departure operations.

The study provided a unique opportunity for a diverse team of operations researchers and the FAA and airline traffic management practitioners to work together on the application of the new optimization techniques and automated decision support tool for solving congestion problems during peak periods at airports.

The STL TRACON and ATC Tower TFM specialists tested the feasibility of the arrival/departure tradeoff optimization model and the decision support tool for a real time, strategic traffic flow management and planning of airport capacity. They found that the tool is potentially beneficial for improving service for air traffic demand, and reducing traffic delays and queues at airports during peak hours. They especially appreciated the fact that the tool provided the opportunities to generate alternative strategies and conduct "what if analyses" that would help them in making the best TFM decisions.

The STL specialists confirmed that it is feasible to vary the airport arrival and departure capacities on a 15-minute basis, thus validating an underlying assumption in the optimization model.

The participants of the study proposed an operational concept of using the tool for strategic TFM decision-making and interaction between the local (TRACON and ATC Tower) and central (ARTCC and ATCSCC) FAA facilities.

During the case study, the STL, FAA, and the airline traffic management specialists agreed that the arrival/arrival departure tradeoff optimization tool is a potentially effective decision support tool for improving utilization of airport capacity, decreasing delays and increasing airport throughput. The participating parties discussed how they would collaborate to make the best TFM decisions based on the optimal strategies generated by the tool.

More case studies will be conducted at other airports before the FAA makes the final decision on deployment of the tool at the FAA facilities. Further plans include enhancement of the optimization algorithm to use additional data provided by airlines including flight-specific data. Another direction targets improvements in the user interface to better assist in the decision-making process.

Appendix. Arrival/Departure Capacity Curves of Runway Configurations at STL

The STL traffic management specialists use the following weather-related operational categories that are determined by ceiling and visibility:

VIS (Simultaneous Visual): Ceiling >= 5000', Visibility >= 5 ml
LDA (Localized Directionally Approach): Ceiling >= 1200', Visibility >= 4ml
ICIA (Independent Converging Instrument Approach): Ceiling 900' – 1200', Visibility >= 4ml
DCIA (Dependent Converging Instrument Approach): Ceiling 400' – 800', Visibility < 4ml
DCIA1: Ceiling 700' – 900', Visibility 2 – 4 ml
DCIA2: Ceiling 400' – 700', Visibility 0.75ml – 2ml
ILS (Instrument Landing System): Ceiling =< 300', Visibility < 0.75ml

The tradeoff areas of the arrival/departure capacity curves for various runway configurations at STL airport are presented in Table A. An explanation of the notation used in the Table A is given below.

Table A. Tradeoff Areas for Various Runway Configurations at STL

Runway Configuration	Weather-related Operational Categories						
	VIS	LDA	ICIA	DCIA1	DCIA2	DCIA	ILS
A 30RL, 24 D 30RL	(8/18 – 18/8)	(12/14 – 14/12)					
A 30RL D 30RL	(8/18 – 18/8)	(12/14 – 14/12)					
A 12RL D 12 RL	(8/18 – 18/8)	(12/14 – 14/12)					
A 30R, 24 D 30L			(11/13 – 13/11)	(10/11 – 11/10)	(9/10 – 10/9)		
A 12R, 6 D 12L			(11/13 – 13/11)			(11/13 – 13/11)	
A 12R D 12L							(8/10 – 10/8)
A 30R D 30L							(8/10 – 10/8)

The range (8/18 – 18/8) denotes a set of "arrival capacity/departure capacity" integer pairs between two extreme pairs: the first one corresponds to minimum arrival capacity (equal to 8) and maximum departure capacity (equal to 18), and the second one corresponds to maximum arrival capacity (equal to 18) and minimum departure capacity (equal to 8). The full set of arrival/departure capacity pairs for this case is shown in Table 1.

The range (12/14 – 14/12) includes the following set of arrival/departure capacity pairs: 12/14, 13/13, and 14/12.

The range (11/13 – 13/11) includes three arrival/departure capacity pairs: 11/13, 12/12, and 13/11.

The range (8/10 – 10/8) also includes three arrival/departure capacity pairs: 8/10, 9/9, and 10/8.

The range (10/11 – 11/10) contains only two arrival/departure capacity pairs: 10/11 and 11/10. Similarly, the range (9/10 – 10/9) contains only two arrival/departure capacity pairs: 9/10 and 10/9.

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Key Words: traffic flow optimization; decision support tool; airport capacity optimization; strategic management of arrival/departure traffic and airport capacity; arrival/departure capacity curve; arrival/departure tradeoff optimization tool; case study, multiple optimal strategies; Collaborative Decision Making.

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