The Departure Regulator: A Working Paper

Isaac Robeson
Georgia Institute of Technology

Dr. John-Paul Clarke
Georgia Institute of Technology

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Abstract

Increased efficiency at airports is necessary to reduce delays and in so doing reduce emissions. Many of the busiest airports in the nation have at least one pair of closely spaced parallel runways, separated by less than 2500 ft, with one runway dedicated to arrivals and the other to departures. Closely spaced parallel runways experience a large decrease in capacity under instrument conditions, because they can no longer operate independently. In order to mitigate this decrease and increase efficiency, we propose a departure regulator for runways with this configuration.

The proposed departure regulator makes use of data from precision tracking systems such as ADS-B to issue automated or semi-automated departure clearances. Assuming sequential departure separations are sufficient for clearance, the regulator will automatically issue or advise the controller to issue the departure clearance as soon as the arrival on the adjacent runway has descended below its decision height. By issuing the departure clearance earlier, the departure regulator reduces the gap between each pair of arrivals that is required to insert a departure. By decreasing the gap, the regulator increases the probability that a departure clearance can be issued.

A simulation was created to model the effects of the regulator and quantify the resulting increases in capacity. Results indicate that all forms of the regulator would provide significant gains of between 13% and 31% in capacity over the current operating paradigm. The results also indicate that the capacity gains are greatest at high arrival rates. Therefore, implementation of the departure regulator could significantly decrease the congestion at many major airports when they are in instrument meteorological conditions.

1 Introduction

Aircraft experience longer taxi times as airports become more congested due to increases in the volume of air traffic. Longer taxi times result in increased fuel burn and emissions. One way to mitigate congestion is to increase the capacity of the runways at the airport. It is with this goal in mind that we propose the development of the departure regulator (hereafter referred to as the regulator) – a tactical air traffic management (monitoring and metering) tool for increasing the capacity of closely spaced parallel runways (CSPR), especially in instrument meteorological conditions (IMC). The regulator was inspired, as described in Appendix A, by the speed gains in the 4x100 meter relay obtained from an acceleration zone not present in the 4x400 meter relay.

The regulator has been designed for use with a pair of CSPR that are configured with one runway dedicated to arrivals and the other to departures. When CSPR are in such a configuration, coupling exists between the arrivals and departures, as a departure cannot begin its takeoff roll if an arrival is within 2 miles of the runway. The regulator works by utilizing data from precision tracking systems such as the Automatic Dependent Surveillance Broadcast (ADS-B) system to issue automated departure clearances as soon as possible after the arrival on final approach to the parallel runway descends below its decision height (DH).

Of the 35 Operational Evolution Partnership (OEP) airports, 19 of them have one or more sets of closely spaced parallel runways, with a total of 26 pairs of CSPR at these airports [1]. These airports are some the busiest in the nation and approximately 75 percent of US passengers pass through them yearly [2]. Thus, increases in the capacity at these airports would result in significant increases in the capacity of the national airspace system (NAS).

To this end, the possible capacity gains due to the introduction of the regulator are determined by modeling and subsequently simulating the interactions between arrivals on one runway and departures on the other runway of a set of CSPR. As the results of the simulation that are presented in this paper demonstrate, there is a potential for large capacity gains with the introduction of the regulator.

2 Literature Review

Because of the large impact that CSPR have on the capacity of airports, especially OEP airports, much has been published concerning methodologies for improving the capacity of CSPR. Yet most of this research focuses on the optimization of arrivals. For example, [3] examines a paired approach procedure to CSPR using ADS-B to longitudinally space aircraft when there are instrument meteorological conditions at an airport. Reference [4] describes a feasibility study performed to consider the possibility of using simultaneous offset instrument approaches at Newark. In [5], the capacity effects of two different proposed simultaneous arrival procedures for CSPR under IMC are considered.

The goal of the proposed regulator is to increase the departure rate for a set of CSPR while at the same time maintaining or increasing the corresponding arrival rate. The net result of such an improvement in the departure rate is an increase in the capacity (the sum of the arrival and departure rate) envelope of the given runway configuration and by extension the given airport. To our knowledge, no such research has been conducted thus far. As a result, much of our efforts, in addition to the obvious ones of defining the concept and developing a concept of operations, has been devoted to determining the capacity increase that would result from the introduction of the regulator.

The capacity of an airport can be determined from empirical data of the historical arrival and departure rates. Reference [6] describes this process and methods for optimizing airports using the resulting capacity curves. In [6], the capacity of an airport is defined as the curve describing tradeoff between maximum arrival and departure rate. The same definition of capacity is used throughout this paper. However, for the purpose of this research, the process of analyzing empirical data could not be used as no data exists for arrival and departure rates with the regulator. Hence the reason why a simulation was developed to calculate the capacity.

3 Background and Motivation

The motivation for the development of the regulator is the prevalence of closely spaced parallel runways. CPSR are found at nineteen of the thirty-five busiest airports in the United States.

Furthermore, at seven of these so-called OEP airports, there are multiple sets of closely spaced parallel runways [1]. Delays at these airports are one of the drivers for delays in the rest of the national airspace system (NAS), so increases in capacity at these airports will help decrease delays throughout the NAS.

Closely spaced parallel runways have three distinct benefits over a single runway in VMC. First, in the case where an arrival is followed by a departure, the departure can be cleared for takeoff as soon as the preceding arrival has landed versus having to wait until the arrival has landed, decelerated, and exited the runway. In fact, the departure can and is often cleared for departure (by the most experienced controllers) when the arrival on the parallel runway has descended below its decision height and is committed to landing. Second, arrivals may be performed independently. Third, departures may be performed independently provided course divergence is assured immediately after takeoff.

Only the first of these three benefits persist in instrument meteorological conditions (IMC). That is, in the case where an arrival is followed by a departure, the departure can be cleared for takeoff as soon as the preceding arrival has landed versus having to wait until the arrival has landed, decelerated, and exited the runway. Additionally, the reduced visibility in IMC typically results in increased conservatism on the part of air traffic controllers. Specifically, they often add time buffers to account for any possible time lags on the part of pilots. The net result is a large decrease in capacity in IMC.

The regulator is designed to recreate, by way of improved sensing and automated clearances, the best situation that exists in VMC. That is, clearing an aircraft waiting for departure on one runway when the arrival destined to the other runway on a pair of CSPR has descended below its decision height. Thus, the regulator will increase capacity in both IMC and VMC, although we expect the increase in VMC to be small when compared to the increase in IMC.

A sample of airports with CSPR is listed in Table 1 with the number of hours that each airport was in IMC for the year of 2009. Only hours where the runway configuration had arrivals on one parallel runway and departures on the other were considered. Also included in this table are the average departure demand and the average unmet departure demand. The numbers in this table were calculated using Aviation System Performance Metrics (ASPM) data for selected airports for all of 2009. ASPM data is collected by the FAA for the purpose of measuring the performance of airports.

Table 1: 2009 IMC Statistics at Sample Airports

Airport	**Hours under IMC**	**Mean Departure Demand**	**Unmet Departure Demand**
ATL	2005	72.4	17.9
DFW	1601	39.5	0.8
EWR	1573	35.1	3.0
LAX	1829	29.3	13.3
PHX	34	28.2	7.0

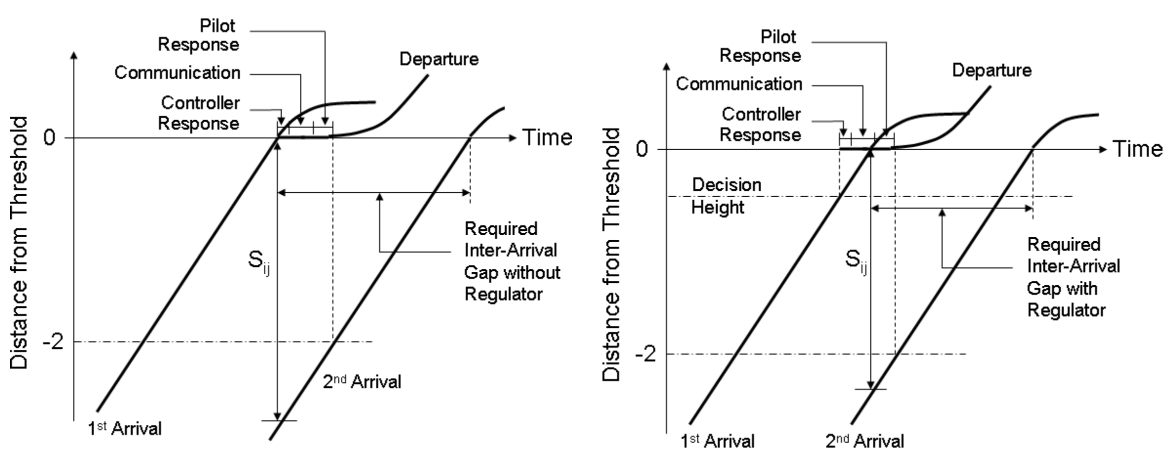
As seen in the table, the number of hours in IMC varies greatly from one airport to another, as does the average departure demand and departure rate. At Phoenix, where IMC conditions are relatively rare, there is little benefit to be gained from runway regulator for improving capacity in IMC. However, at Newark and Atlanta airports, there is both a large unmet depature demand as well as a significant amount of time in IMC. Therefore, at both airports, significant gains could be made when operating in IMC.

4 Preliminary Concept of Operations

The regulator was conceived with the following preliminary concept of operations. The local controller (who operates from the airport control tower) will instruct by way of a clearance the departing aircraft to line up and wait on the departure runway. Then, if sufficient separation exists between the current departure and the previous departure, the regulator will issue an automated or semi-automated clearance once the arrival on the adjacent runway has descended below its decision height. The automated takeoff clearance may take the form of an automated voice clearance and/or visual signal using lights on the runway. In the case of a semi-automated clearance, the controller would be provided a signal by a decision support aid indicating that the arrival on the adjacent runway has descended below the decision height.

Currently an arrival and a departure must be separated by a minimum of two miles and the separation must increase to three miles after takeoff before a departure clearance can be issued by the tower [7]. This requirement specifies that the separation must be determined at the time when the departure begins its take off roll. So a controller must ensure that enough time exists for a clearance to be issued and the pilot to respond and begin takeoff roll before the arrival crosses the two mile boundary [7].

Once an arrival is within the two mile threshold, the departure can only be granted clearance once the arrival has touched down and there is enough separation from the previous departure. Introduction of the regulator does not require relaxation of the two mile separation requirement, but it does relax the touchdown requirement. Specifically, the automated departure clearance is issued as soon as it is detected that the arrival has descended below the decision height and there is enough separation between the current departure and the previous departure.



(a) Standard Operations.

(b) Regulator Operations.

Figure 1: Diagram of Closely Spaced Parallel Runway Operations under IMC

Figures 1(a) and 1(b) illustrate the reduction due to the regulator in the minimum inter-arrival gap required for a departure to takeoff. Shown in these two figures are the interactions between two arrivals and a departure with standard IMC operations and IMC operations with the regulator. As seen in Figure 1(a), with standard IMC operations, for an aircraft to be able to depart between two arrivals, the inter-arrival gap must be large enough that the time between the leading arrival touching down and the trailing arrival passing the 2 NM boundary is sufficient for the departing aircraft to begin rolling. For a departing aircraft to begin rolling, the controller must observe the leading aircraft touch down and then communicate the clearance to the pilot. The pilot must then communicate acknowledgement of the clearance, and then respond to the clearance by taking action to begin take-off roll.

However, as seen in Figure 1(b), the inter-arrival gap necessary for an aircraft is smaller with the regulator. The regulator decreases the size of the gap by shifting the start of the takeoff procedure to an earlier point in time, namely the time when the leading arrival descends below the decision height. Therefore, the inter-arrival time can be shorter, while still allowing a departure to takeoff between the arrival pair.

The result of the smaller required inter-arrival gap with the regulator is that there is a greater probability that a large enough gap will exist for a departure to be cleared for takeoff. In other words, the separation between a pair of arrivals, Sij, can be less with the regulator and still allow for a departure to takeoff. Therefore, at a given arrival rate, the departure rate will be greater when the regulator is implemented than when current standard separation requirements are applied.

Another advantage of the runway regulator is that it allows an arrival to cross the departing runway without having to stop to wait until the departure has crossed the intersection as the departure will have already passed that taxiway intersection. With the regulator, as the arrival is slowing and exiting the arrival runway, the departure is taking off, thereby clearing the departure runway. The arrival can then be immediately cleared to cross the departure runway if necessary, thereby helping to reduce congestion on the taxiways.

4.1 Clearance Methods

Departure clearance can be issued in either a semi-automated or fully automated manner. The semi-automated clearances would be issued by providing the controller with a decision support tool and then the controller would issue the clearance as normal. The automated clearance could take the form of voice clearances generated by a computer based on the flight number and the runway number. The generated clearance would then be broadcast via existing HF channels. Alternatively, lights on the runway or on either side of the runway could be used as visual cues to the pilot that they should begin takeoff roll. These runway lights would change from red to green when the arrival has descended below the decision height and the departure has clearance. A visual cue could be used in conjunction with voice clearances.

Of these three options, the semi-automated clearance, where the controller is notified and then issues the clearance, differs the least from current operations. In this form, the regulator would simply function as an aid to controllers. Using only the runway lights to issue the clearances departs the most from current operations. However, this method significantly cuts down on response time to a clearance being issued. Instead of listening to a clearance and then responding with confirmation to the clearance and then throttling up, a pilot only needs to respond to a visual signal and throttle up, thereby greatly reducing the response time.

4.2 Missed Approaches

The decision height is the altitude at which a pilot must be able to see the runway and commit to a landing; otherwise, the pilot must execute a missed approach. The decision height varies based on the landing aids available on the aircraft and at the airport in question, the terrain and buildings around the airport, and any agreements authorities might have with local residents. These factors determine which category of ILS procedures may be flow at specific airports. For each category of ILS approach, the FAA has specified minimum heights above the threshold that the decision height may be [8]. These heights are listed in Table 2.

Table 2: Minimum Decision Heights

ILS Category	Minimum Decision Height
Cat. I	200 ft
Special Cat I	150 ft
Cat. II	100 ft
Cat. III	0 ft

For the purposes of the analysis to follow, for approaches with decision heights greater than 200 ft, we assume that the clearance is issued as soon as possible after the arrival has descended below 200 ft.

Because a pilot must be able to see the runway and be in the appropriate configuration and attitude for landing at the decision height, the number of missed approaches executed once an arrival has descended below the decision height is very low.

On the rare occasion a missed approach is started below the decision height, an automated abort takeoff command will be issued to the departure. Because of the short time between the decision height being reached and the arrival touching down, the departing aircraft will not have reached V1 by the time the arrival initiates the missed approach. Recall that V1 is the speed at which a pilot must continue takeoff even in the case of engine failure. As such, it is the maximum speed from which a pilot can brake and still stop safely.

A decision height of 200 ft and a glide slope of 3 degrees correspond to a flight path distance of 0.63 NM. At an arrival speed of 130 knots, an aircraft would cross the decision height and touch down in approximately 18 seconds. The worst case scenario with regards to a missed approach is that clearances are being issued using the automated runway lights. In this case, there is no controller response time or controller-pilot communication time. Therefore, the only delay between an arrival descending below the decision height and the departure beginning takeoff roll is the pilot response time. Assuming a 5 second pilot response time, only 13 seconds is left for the aircraft to accelerate beyond V1. However, assuming that the aircraft has a constant acceleration rate down the runway and rotates at 5000 feet down the runway, it will take approximately twice that amount of time to reach V1. Therefore, a takeoff can still be aborted if a missed approach is executed below the 200 ft decision height.

Further risk analysis is needed to ensure the safety of the regulator. Nevertheless, given the rarity of missed approaches below the decision height and the limited time between the decision height and touchdown, the preliminary analysis indicates that the regulator can be implemented safely. If further analysis reveals that 200 ft is too early along the arrival path, the maximum decision height could be lowered to further decrease the time between the decision height being reached and touchdown.

5 Simulator Description

The possible capacity gains due to the introduction of the regulator are determined by modeling and subsequently simulating the interactions between arrivals on one runway and departures on the other runway of a set of CSPR in IMC. The simulation iterates through arrival and departure queues to determine the maximum departure rate at a given arrival rate. The results of this simulation are used to generate capacity curves to demonstrate the increase in capacity with the regulator.

The simulation begins by assigning one runway to arrivals and the other to departures. For each runway, a random sequence of aircraft waiting to utilize the runway is generated. These queues are generated using the fleet mix at the airport being studied. The fleet mix establishes the percentage of each of the four wake turbulence classes that frequent the airport. The four wake turbulence classes specified by the FAA are small, large, B757, and heavy.

After the two sequences have been generated, the arriving aircraft are spaced out so that the required separations are maintained at the runway thresholds. These separations are listed in Table 3.

Table 3: Separation between Arriving Aircaft [7]

		Trailing Aircraft			
	(nmi)	**Small**	**Large**	**B757**	**Heavy**
Leading Aircraft	**Small**	2.5	2.5	2.5	2.5
	Large	4	2.5	2.5	2.5
	B757	5	4	4	4
	Heavy	6	5	4	4

Once the minimum spacing between each arrival pair has been calculated, an additional random separation is added between each arrival pair. This random separation has an exponential distribution with a probability density function as shown in Equation 1. With each run, λ is decreased to test the regulator over a range of arrival rates, from the maximum arrival rate to effectively no arrivals.

$$f(n) = \begin{cases} \lambda e^{-\lambda t} & \lambda \geq 0 \\ 0 & \lambda < 0 \end{cases} \tag{1}$$

For each run, the separations between each arrival pair is converted into a time separation by assuming an average arrival speed on final approach for each weight class. The average speeds are listed in Table 4. Using these speeds, the times at which each arriving aircraft crosses three points are calculated. These three points are located 2 NM from the departure awaiting clearance, at the decision height, and at the runway threshold. To calculate the corresponding times, a 3 degree glide slope is assumed.

Table 4: Average Arrival Speed [9]

Small	**Large**	**B757**	**Heavy**
90	130	130	150

6 Modeling Controller-Pilot Interactions

The values used to model the response and communication times of the controllers and departing pilots are listed in Table 5. For each pair of arrivals, a total response and communication time is calculated based on the numbers in this table and the form of the clearance being used by the regulator. If the total response and communication time is greater than the time available to start the takeoff roll, the departure is not given clearance. The available time is the time interval beginning with either the leading arrival descending below the decision height for the regulator or the leading arrival touching down for current operations and ending when the trailing aircraft reaches the 2 NM boundary.

Each communication or response time is modeled as a normal distribution with a lower bound. If a time less than the lower bound is generated, the normal distribution is resampled until a time greater than the lower bound is generated.

Table 5: Response and Communiction Times

	Mean	**Standard Deviation**	**Minimum**
Controller Response	1.0 sec	0.25 sec	0.25 sec
Controller Communication	4.0 sec	1.0 sec	2.0 sec
Pilot Communication	5.0 sec	1.0 sec	2.0 sec
Pilot Response	5.0 sec	1.5 sec	2.0 sec

The communication times are based on observations of communications between pilots and tower controllers issuing clearances, as well as studies of communications in the en-route sector [10]. While the numbers for communication times between the tower and departures may differ from en route communication times, the en route times provide a baseline approximation for the tower communication times.

The controller response time is the time it takes for the controller to recognize either that an arrival has touched down or to observe the automated signal that the arrival has descended below the decision height. This response time is only used when modeling baseline conditions or the semi-automated regulator where the controller is cued to issue the clearance.

The controller communication time is the time required to verbally issue the departure clearance. This communication time is included in all versions of the simulation, except when simulating the regulator using runway lights to issue the clearances.

The pilot communication time is the time required for the pilot to communicate acknowledgement of the clearance. This includes any lag between the end of the controller issuing the clearance and the pilot starting to reply. The pilot communication time is also included in all simulations except simulations modeling the regulator which is using the runway lights to issue clearances.

The pilot response time models the time from the end of the pilots acknowledgement of the clearance to the start of takeoff roll. This time includes the time it takes to spool up the engines.

6.1 Modeling Departures

The departure queue is always assumed to be full so that the maximum departure rate can be achieved. A departure is allowed to takeoff whenever there is a large enough gap in the arrival stream and the previous departure has gained enough separation.

As described above, a departure must be separated from an arrival on final approach by at least 2 NM and that separation must grow to 3 NM within 1 minute after take off [7]. Under current regulations in the case of closely spaced parallel runways, the departure cannot begin its takeoff roll until the arrival on the parallel runway has touched down. However, as described above, with the regulator, the departure is allowed to begin its takeoff roll once the arrival has descended below the decision height.

For departures on the same runway, before a trailing departure can begin its takeoff roll, the previous departure must be at least 6000 ft down the runway and airborne [7] for the aircraft types considered in the study. When the leading departure is a heavy jet or a Boeing 757, the trailing aircraft must wait at least 2 minutes before beginning its takeoff roll [7]. Also, departures must be sufficiently spaced to ensure proper separation in the TRACON area. When departure courses diverge immediately after departure by at least 15 degrees, departures only need to be spaced by 1 mile [7]. Otherwise, the minimum separations between departures along the same course within 40 miles of the radar antenna are listed in Table 6.

Table 6: Separation Between Departures

		Trailing Aircraft			
	(nmi)	**Small**	**Large**	**B757**	**Heavy**
Leading Aircraft	**Small**	3	3	3	3
	Large	3	3	3	3
	B757	5	4	4	4
	Heavy	5	5	4	4

In order to determine the required minimum time between each departure, an average departure ground speed is assumed for each weight class of aircraft. These speeds are listed in Table 7. Each aircraft is assumed to accelerate at a constant rate so that it reaches its average departure ground speed at a point 5000 ft down the runway [9]. It is assumed then to maintain that constant ground speed during climb [9].

Table 7: Average Depature Speed [9]

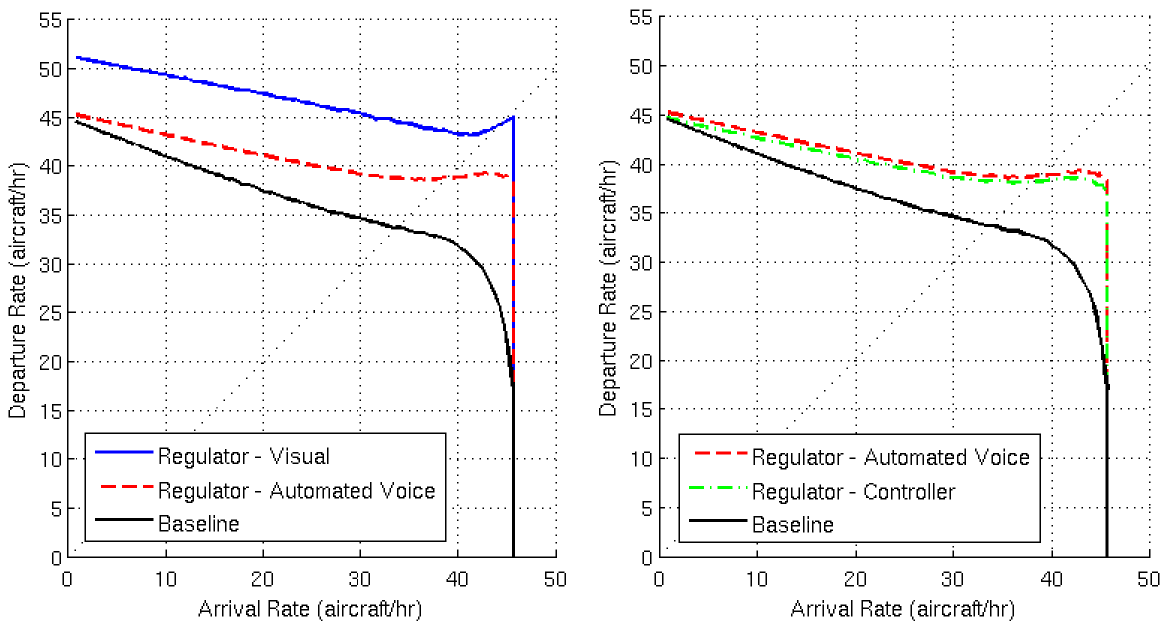
Small	**Large**	**B757**	**Heavy**
100	150	150	170

6.2 Analyzing the Results

Once the arrival queue has been spaced out and iterated through with a departure being allowed to depart whenever possible, the throughput of the CSPR for each run of the simulation is calculated from the number of arrivals and departures, and the time required to empty the arrival queue. Multiple runs of the simulation are made with varied distributions of the random arrival-arrival separation in order to calculate the maximum departure rate at a range of arrival rates.

7 Results

Simulation results indicate that there would be large capacity gains for CSPR in IMC when operating with the proposed regulator. See Figures 2(a) and 2(b). In both plots, the baseline curve represents the capacity of a set of CSPR under current operations in IMC. The capacity increases with the two automated forms of the regulator are shown in Figure 2(a). In Figure 2(b), the capacity gains with the semi-automated form of the regulator and the automated form that uses voice clearances are shown to illustrate the effect of controller delay, both in observation and reaction. In all of these plots, the decision height used by the regulator is 200 ft.



(a) Automated Clearances. (b) Voice Clearances.

Figure 2: Capacity of CSPRs with and without the Regulator

All three forms of the regulator provide significant increases in capacity. These increases are as a result of two phenomena. First, as was explained earlier (see Figure 4), the regulator effectively reduces the gap between arrivals required to insert a departure allowing for gains in the total capacity, because the probability of finding a gap that enables at least one departure increases. The net result is that the departure rate decreases slower with increasing arrival rate compared to the baseline case. Second, as the arrival rate increases, the number of inter-arrival gaps that enable two or more departures decreases. At some threshold rate, the vast majority of the inter-arrival gaps will only enable one departure. Even though the gaps might be wider than the required gap for one departure, they are less than the required gap for two. The net result of this phenomenon is the unexpected behavior that the departure rate actually increases slightly with increasing arrival rate, because the regulator has synchronized the departures with the arrivals. In other words the arrivals and departures are executed in lock step with each other. This increase continues until the arrivals become too tightly spaced and the departure rate once again begins to drop off. The percentage increases in throughput when the set of CSPR has balanced operations, i.e. when the arrival and departure rates are equal, are listed in Table 8.

Table 8: Clearance Method Throughput Increases

Clearance Method	ThroughputIncrease
Visual	31%
Automatic Voice	15%
Controller	13%

The largest capacity gains occur when visual cues (runway lights) are used. This gain is greater than in the other two cases because controller response and the communication time are eliminated. There is a small capacity gain with automated voice clearances over signaling the controller and allowing the controller to issue the clearance. This gain occurs because with automated clearances there is no delay between the earliest time that a clearance can be issued and the time that the clearance is issued. However, this delay is minimal with this simulation; thus, the gains are small. That being said, it is important to determine what the true controller-pilot interaction delays would be through human-in-the-loop simulation. Once the delays are known, the simulation can be used to derive revised capacity estimates.

Note that when controllers issue the clearances with and without the regulator, the capacity for both cases is the same when there are only departures. This result is expected as, under these conditions, the mean time for a clearance to be issued and a departure to begin takeoff roll is identical for both cases. As the arrivals are sparse, there are no gains to be had with the regulator.

7.1 Effects of Decision Height

As the decision height decreases, the benefits of increased capacity are decreased, as shown in Figure 3(a). The percent throughput increase with each decision height is listed in Table 9. The percent throughput is calculated when there are balanced operations on the runway. As can be seen, there are still significant benefits even with a decision height of 50 ft. The semi-automatic version of the regulator was used to generate these curves.

Table 9: Throughput Increases at Various Decision Heights

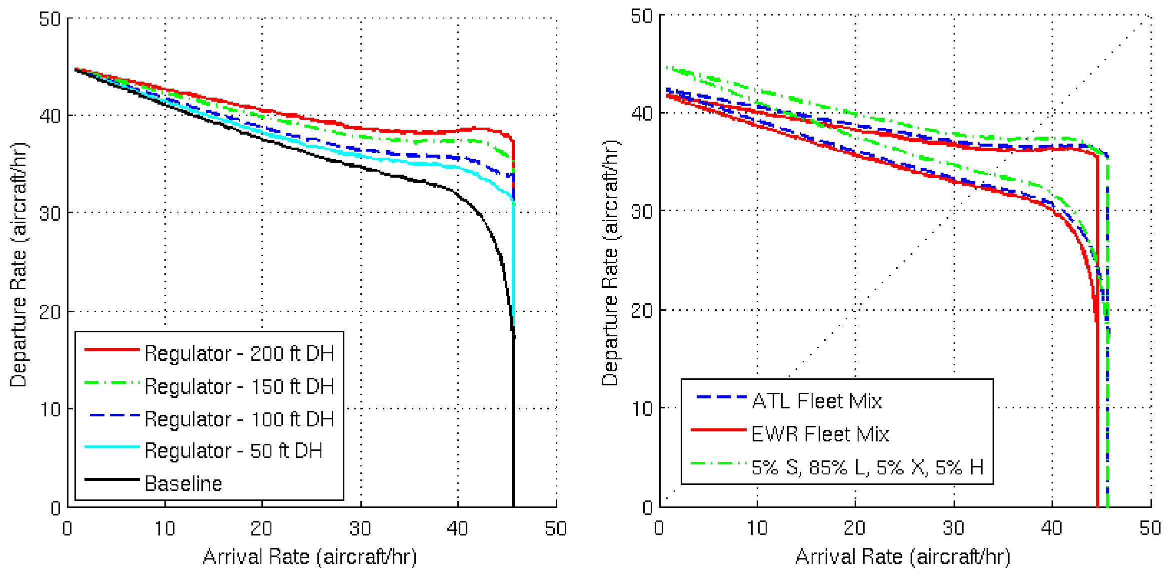
Decision Height	ThroughputIncrease
200 ft	13%
150 ft	11%
100 ft	6%
50 ft	4%

Table 10: Fleet Mix at Example Airports

	ATL	EWR	Baseline
Small	1.0%	1.4%	5%
Large	79.8%	77.2%	85%
B757	12.75%	11.3%	5%
Heavy	5.9%	9.7%	5%

7.2 Effects of Fleet Mix

The spacing between both arrivals and departures depends greatly on the aircraft weight classes. Thus, the capacity at an airport greatly depends on the percentage of each class that frequents that airport. Listed in Table 10 are the fleet mixes at Atlanta and Newark during the month of January in 2009 as calculated from ASPM data. Included in the table is the fleet mix of the baseline case used to generate the plots presented thus far.



(a) Decision Height Effects.

(b) Fleet Mix Effects.

Figure 3: Effects of Decision Height and Fleet Mix on Capacity

The changes in the airport capacity as a function of the fleet mix are illustrated in Figure 3(b). For each fleet mix, the capacity curves with and without the regulator are shown. The higher capacity curve is always the capacity with the regulator. For these runs, the semi-automated regulator was used and the decision height was 200 ft. As seen in this figure, while changes in fleet mix do shift the results, the regulator always provides increases in capacity.

8 Conclusion

The potential for large capacity gains through the use of the proposed departure regulator has been demonstrated through simulation runs. The simulation model was designed to mimic current FAA regulations. Automated clearances using runway lights offers the greatest potential for gains in capacity, but this method departs the most from the current operating paradigm. Introduction of a decision support tool that cues the controller offers significant, albeit smaller, gains and has the added benefit that it fits well with the way runways are currently managed. The decision height plays a significant role in the capacity gains of the regulator, but even with low decision heights, significant gains in capacity are available. These gains are present under a range of fleet mixes as well.

The large capacity gains with the regulator are due to the fact that the regulator allows a departure to takeoff in a smaller gap between departures. Thus, there are more gaps in an arrival stream allowing a departure to takeoff. The regulator creates the situation where the maximum departure rate possible increases with increased arrival rate, when the arrival and departure rates become approximately one-to-one. This gain in departure rate occurs near the peak arrival rate allowing for increases in capacity even under heavy demand.

Further testing will be performed to confirm these gains and to validate these results. These tests are expected to include more accurate simulation of the regulator and human factors studies with pilots and controllers to determine the effectiveness of the regulator, as well as to identify and address implementation issues.

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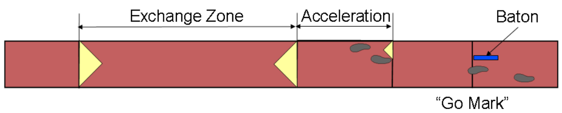
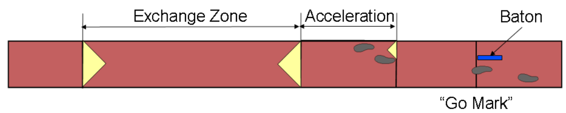
A Inspiration for Departure Regulator

The inspiration for the regulator came from the realm of track and field, specifically the differences between the 4x100 meter relay and the 4x400 meter relay. In both types of relays, the runners must exchange the baton within an exchange zone that is 20 meters in length, as seen in Figures A. In the 4x400 meter relay, the outgoing runner must begin moving from a stationary position inside the exchange zone, as seen in Figure 4(a). In the 4x100 meter relay however, the runner receiving the baton has an acceleration zone of 10 meters prior to the exchange zone, as seen in Figure 4(b). The outgoing runner uses this additional 10 meters to accelerate and attain the same traveling speed of the incoming runner.

This difference results in exchanges at high speed in the 4x100 meter relay, whereas the exchanges in the 4x400 meter relay occur at comparatively lower speeds. As a result, the times for the 4x100 meter relay are faster than the sum of the individual runners times, while the same cannot be said for the 4x400 meter relay.



(a) 4x400 Relay.



(b) 4x100 Relay.

Figure 4: Capacity of CSPRs with and without the Regulator

The 4x400 meter relay is analogous to the current situation with CSPR. When a departure on one runway follows an arrival on the other runway, the departure must wait for the arrival to touch down and thus has no acceleration zone. Consequently, the exchange between the two aircraft (which begins when the arrival is first adjacent to the departure and ends when the arrival is last adjacent to the departure) occurs at relatively low speed. The regulator creates a situation similar to the 4x100 meter relay by allowing the departing aircraft to begin its takeoff roll before the arrival touches down, effectively creating an acceleration zone for the departure. As a result, the exchange occurs at a higher average speed.