Resolving the Impact of Variance on Flight Times and Delays

GreenLandings™ mitigates flight time variance, incorporates aircraft operators' and Air Traffic Management firms' business rules and preferences, continuously solves the real-time, system optimization problem for flight trajectories, which improves safety, reliability, operating economics and reliability, environmental signature, customer and employee outcomes, and permits operators to create a virtuous cycle of feedback into future operations planning, effectively increasing airspace, ATC and airfield system capacity and performance, recovering stranded flight and ground equipment buffers and labor capital, improving utilization and creating new revenue opportunities.

The Source of Variance

Dynamic instability is a condition in which a system or process is not able to maintain equilibrium. This may be caused by internal changes, external disturbances, or a combination of both.

When a system or process is dynamically unstable, the variance of its output will increase, producing output values that are further from the mean.

In general, variance is natural occurrence of dynamic instability in continuous systems or processes. The more unstable a system is, the greater the variance of its output.

In the ground and flight time example, the consequence of internal factors such as cost index, differences in operating weights, flight plan routing, aircraft rigging and performance, and flight management will cause variance in enroute flight times.

External factors such as winds aloft, weather encounters, controller commands, conflicting traffic avoidance, company requests and asset shortages (gates, servicing, handling) will cause variance in ground and flight times.

The greater the cumulative variance, the more difficult it is to control flight time outcome.

The control for dynamic instability in the flight time context is GreenLandings™ real-time trajectory optimization, based on system-level, continuous airspace complexity assessment, trajectory forecasting, robust algorithmic optimization, and issuance of improvement advisories.

The Impact of Variance on Flight Times

In probability and statistics, variance is a measure of how widely distributed are the values in a data set, such as actual flight times in a market at a certain time of day.

Let's take the example of the distribution of actual flight times in a market for a certain time of day departure, say the published, scheduled 9:00 AM local time departure of flights between JFK and LAX, scheduled to arrive after 6 hours and 20 minutes, at 12:20 PM local time. The almost ten percent of Teterboro flights (and a multiple of that percent of flight hours) operated transcontinental to Van Nuys, San Francisco, Boeing Field, Las Vegas, Ontario, San Jose and similar, would mirror this experience.

The actual flight time on any given day-of-flight will differ for a variety of reasons that include aircraft load, performance, winds aloft, conflicting traffic, departure gate delay, taxi out time, enroute time, taxi in time, and arrival gate delay.

Variance and the flight operator's business rules can tell us how this flight's 6 hour and 20 minute published time was chosen and published for internal olanning purposes and external customer reference and use. .

The 'shape' of the 0900 JFK-LAX flight time data set tells us something about the nature of the data, whether it is clumped, occurring with great certainty, or appears random, varying widely.

If all actual flight time data set values were the same, all values equaling the mean, there is no dispersion, variance is zero, flight time is achieved with great certainty, and termed deterministic.

This would be the case if the scheduled 0900 JFK-LAX flight time was actually achieved each day. All example flights would depart on-time, take exactly 6 hours and 20 minutes, and actually arrive on-time at 12:20 local time.

A low variance means that actual values are highly concentrated around the mean.

A high variance means that actual values are widely dispersed, spread over a wide range surrounding the mean.

In practice, the data set of actual flight times is a probability distribution that appears random, ranging from the minimum achieved time, say 5 hours and 30 minutes, to the longest experienced time, say 7 hours, with a central tendency or peak at 6 hours.

Actual data sets of random outcomes approximate normal distributions, though some have a long tail reflecting a significant probability very long flight times, worst case outcomes.

The mean and variance are two important measures of central tendency and dispersion. They are used to describe the distribution of data and to compare different data sets.

The Impact of Variance on Flight Delays

Queueing Theory is a branch of mathematics that deals with the study of waits for service, or queues. Queues, in our example, are customers or flights waiting to be served or handled.

In our context, a queue might be passengers waiting to board, leave and arrive, or the aircraft operator for all services, doors and compartments to be completed and secured, depart blocks, push-back, taxi-out, take-off, transit an enroute sector, fly an approach, taxi-in, wait for an arrival gate, brakes set at blocks, or wait for an agent to open the cabin door on arrival for deplaning and post-flight servicing.

Queuing Theory informs how variance in demand rates for service/handling, and variance in time to complete service/handling processes affect delays.

In general, low variance helps improve customer satisfaction and retention. Customers are more likely to be satisfied if they can expect very consistent processes and flight times, relatively few and brief delays that are relatively consistent. For the aircraft operator, low variance in process and elapsed times typically result in lower handling and service costs, with improved capital utilization and revenue retention.

By contrast, high variance in demand or process times drive a greater chance that any queue or service will be long, which will lead to higher costs, longer dwell, elapsed time, and delays, higher costs, lower utilization, customer frustration, poor customer satisfaction, and reduced likelihood to re-purchase.

In our airline and air traffic demand handling context, the likelihood of delays requires schedulers to think about what scheduled flight times to plan and publish, and air traffic handling staff to think about what arrival and departure rates to publish, such that airlines, customers and air traffic handling staff can rely on published planning times with greater certainty.

For example, consider an air traffic handling system with an average arrival rate or demand of one flight per minute, equaling capacity. If the variance of the arrival rate is low, demand nearly deterministic, matching handling capacity, any queue will typically be short, and flights will typically experience short delays. However, if the variance of the arrival times is high, then queues will sometimes be long, and aircraft operators and customers will sometimes experience long delays.

Because aircraft operators must plan operations, given availability and utilization of their capital equipment to be feasible and relatively certain, and typically compete with others on metrics like ‘on-time performance’ (such as the DOT A-14 measure) they typically over-estimate, buffer, or ‘pad’ service and flight times. This reduces revenue utilization of equipment, but is done to attempt to ensure greater ‘on-time’ performance. If the results are still unfavorable, lengthy delays and continuing poor A-14 'on-time', more pad is introduced until the target A-14 is achieved.

Baking pad into schedule times completes a destructive cycle that consumes equipment and labor utilization and revenue productivity. This is a very expensive way to reduce variance and achieve improved results.

The method by which planners do this is to decide what 'on-time' percentage they wish to target, look at the distribution of historically achieved times, and choose that specific time on the cumulative probability curve that statistically captures, say, 85% of outcomes, meaning 85% of historical flight times less than or equal to that value.

Thus, an achieved average 50% cumulative probability time 0900 JFK-LAX of 6 hours flat becomes 6 hours and 20 minutes in order to achieve an A-14 on-time result with an 85% certainty. The 'pad' is 20 minutes.

On a transcontinental flight, where enroute time is the bulk of elapsed time and normally distributed, this 'pad' may be 5-6% above the average flight time.

In highly congested northeast corridor short haul markets, where the bulk of variance is in ground and terminal area processes, the 'pad' may represent in excess of 30% above average flight time. Almost twenty percent of Teterboro departures are in short-haul, northeastern US markets including Dulles, Bedford, Boston, White Plains, Baltimore, Philadelphia, Republic, LaGuardia, JFK, and would

In general, it is desirable to actively reduce the variance of arrival/demand rates in a queueing and service system. Reducing variance keeps queues shorter, reduces the instances and length of delays, reduces average achieved elapsed/dwell time, and eliminates the need for buffers or 'pad'.

Further, feeding back actively improved achieved results to the schedule and flight planning process improves capital efficiency and utilization in a virtuous cycle of improvement.

GreenLandings™ employs techniques to reduce demand/arrival variance, making small changes to demand rate via arrival timing and also re-sequencing arrivals to meet flight operator business rules.

The most comprehensive use of GreenLandings™ involves system optimization of all flights enroute to a regional terminal area, airport corner post or arrival fix, maximizing benefits to all flight operator users and ATM/airport servers, while disadvantaging none.

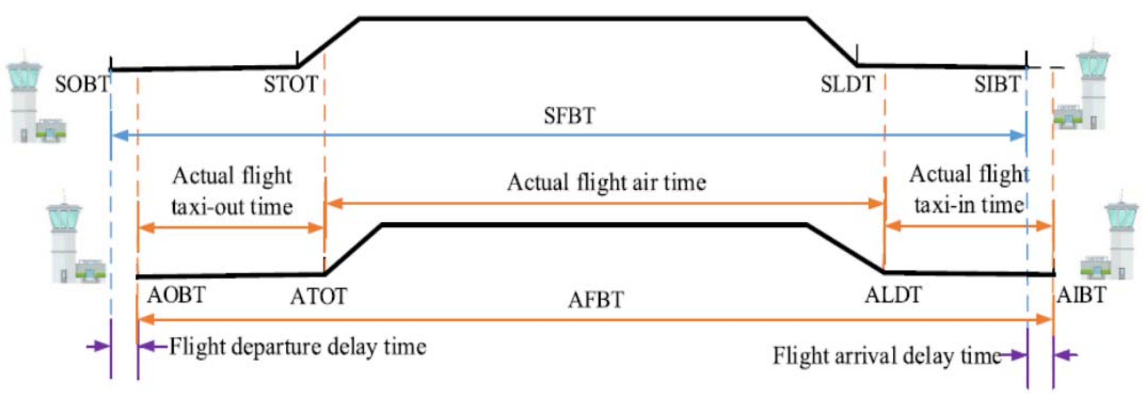
Initial GreenLandings™ actions for aircraft operators could include:

- Modestly re-timing arrivals. GreenLandings™ advising customers at what times they may plan to arrive to eliminate or minimize delays.
- Using a realtime optimization system. GreenLandings™ advising customers enroute that a small change in aircraft speed or arrival time ensures they arrive to eliminate or minimize delays.
- Offering incentives for customers to participate in planned re-timing and real-time optimization. GreenLandings™ participation benefits all users, and should be rewarded.

With GreenLandings™ reducing aircraft arrival rate variance, introducing order and determinism in arrival rates, the performance of a queueing system improves, the ease of ATC handling increases, reducing the requirement for ATC intervention, reducing aircraft operators' costs, improving customers/employees' outcomes and satisfaction.

Quantitative examples of how operators presently act and how GreenLandings™ could improve operator and customer outcomes follow.

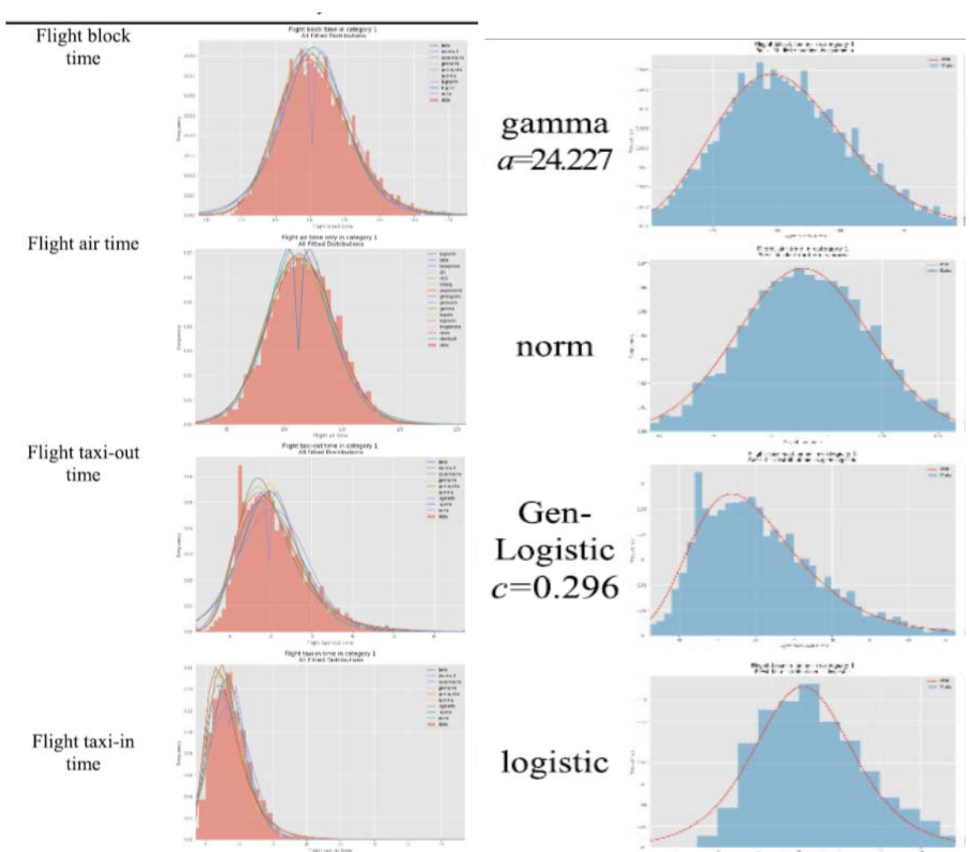
Scheduled and actual flight block time phases, including gate, ground and flight components might be broken down as follows:



A typical operator's historical data would show a random distribution of actual results in a given market and time of day. The actual time distribution evidences a minimum achieveable time, a distribution of results about the mean value, with a long tail including worst case experiences, despite what is for operating plan and marketing purposes a given, deterministic, planned and published outcome.

The given value is typically inflated by use of a buffer of ‘pad’ to account for observed variability in results, to improve reliability of following flights, the prompt dispatch of which depends on the prior aircraft arrival time, to adjust passenger expectations of arrival times based on which they set their own schedules, and to meet competitive statistical goals on DOT A-14 on-time metrics, an example fo which might be “better than 85% A-14”.

A distribution of actual results along with best fit probability functions, follows:



Flight Block Time Distributions and Best Fit PDF By Phase of Flight (OOOI)

The impact of experienced random outcomes on flight operator schedule planning and equipment utilization is illustrated in the following chart of long-haul, medium-haul and short-haul markets.

Using average experienced flight times, a Gamma probability distribution for overall results, and seeking an 85% or 90% on-time (A0) performance, the operator might pad long-haul flights by from 19 to 25 minutes, medium haul flights by from 12 to 16 minutes, and short-haul flights from 7 to 10 minutes.

While these pads may seem modest, they represent a lost utilization latency of from 9 to 13 percent, meaning the impact on capital equipment and labor utilization is significant.

Given a long-haul aircraft may operate 3 legs daily, a medium haul aircraft 5 legs daily, and a short-haul aircraft 8 legs daily, the effects on the economics of the operation are likewise significant.

On a 100 aircraft fleet, this represents an effective cost or loss of from 10 to 13 aircraft, hundreds of millions of dollars of stranded flight and ground capital, and 30 to 60 or more flight crews, 60 to 120 pilots, and additional cabin and ground crew.

GAMMA CDF	EXAMPLE MARKET	SCHED MIN	AVG MIN	SCHED PAD	PAD%	LEGS DLY	PAD LATENCY	100 FLEET IMPACT
	TRANSCON							
84.2%	TEB-VNY	379	360	19	5.3%	3	9.5%	10
85.4%	TEB-VNY	380	360	20	5.6%	3	10.0%	10
90.4%	TEB-VNY	385	360	25	6.9%	3	12.5%	13
	SEMI-TRANSCON							
83.7%	TEB-PBI	162	150	12	8.0%	5	10.0%	10
85.5%	TEB-PBI	163	150	13	8.7%	5	10.8%	11
90.1%	TEB-PBI	166	150	16	10.7%	5	13.3%	13
	SHORT-HAUL							
83.1%	TEB-IAD	61	54	7	13.0%	8	9.3%	9
86.1%	TEB-IAD	62	54	8	14.8%	8	10.7%	11
90.8%	TEB-IAD	64	54	10	18.5%	8	13.3%	13

The Impact of Variance on Airspace Complexity

Airspace complexity is a 4-D space and time queueing example of the general queuing model discussed above, where at any given airspace loading (arrival rate or demand on a sector), increasing the variance or arrival rates drives greater airspace complexity, while reducing arrival rate variance reduces complexity -- and/or allows greater airspace loading with no increase in complexity.

GreenLandings™ is the AI capability that controls and reduces dynamic instability in the flight time context.

GreenLandings™ is real-time trajectory optimization, based on system-level, continuous airspace complexity assessment, trajectory forecasting, robust algorithmic optimization, and issuance of improvement advisories.

Dynamic instability due to variance in aircraft trajectories, 4-D airspace complexity, and trajectory optimization to reduce instability, are challenging problems in aerospace engineering, involving the design and realtime management of trajectories that are stable and robust to disturbances, while also taking into account the four dimensions of airspace and flight vehicles -- time, position, velocity, and acceleration.

The problem is made more complex by the fact that the dynamics of flight enroute can be nonlinear and time-varying. This means that equations that describe and forecast flight trajectory are very complex, and solutions to these equations change over time.

In addition, the number of degrees of freedom in a flight trajectory can be very large, meaning there are many different ways the trajectory can change, and it can be difficult to find any given trajectory that is optimal in all respects, over time.

Finally, the disturbances or other variances that a flight can encounter are often unknown or uncertain. This means that it is difficult to design a forecast trajectory that is robust to all possible disturbances, on the ground or inflight.

Despite these challenges, dynamic instability and 4D complexity trajectory optimization are important problems with a wide range of applications, including aircraft operation.

GreenLandings™ solves aircraft operators' and Air Traffic Management firms' real-time, system optimization problem for flight trajectories, which improves safety, reliability, economics, environmental signature, and customer response, and permits operators to create a virtuous cycle of feedback into future operations planning, effectively increasing system capacity and performance, recovering stranded flight and ground equipment and labor capital, improving utilization and creating new revenue opportunities.

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