Selecting Parameters in Performance-Based Ground Delay Program Planning

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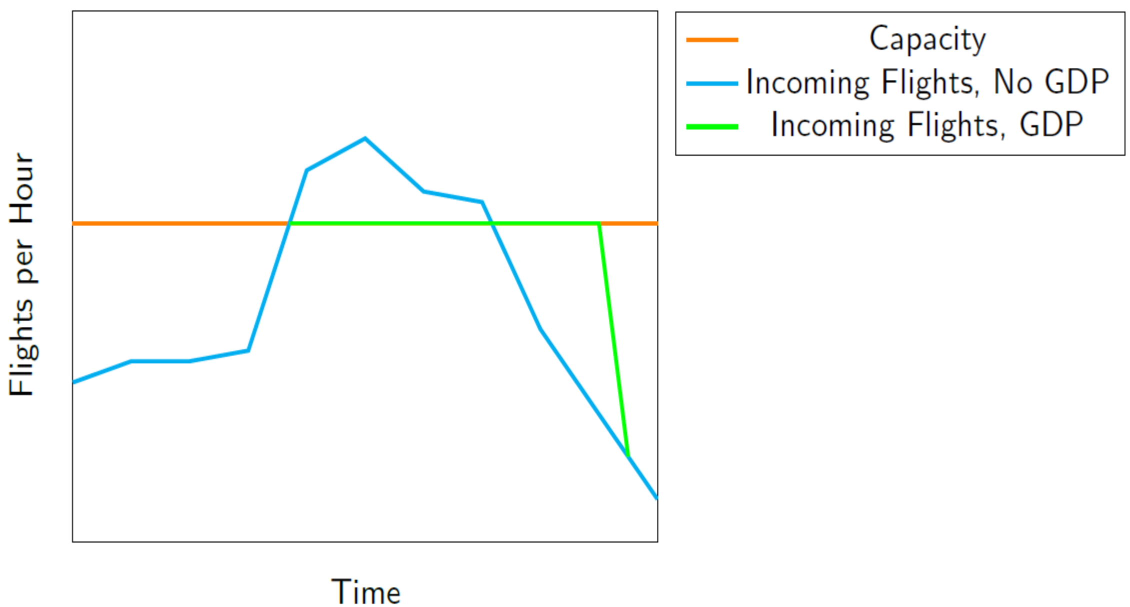
Research funded by NASA grant no. NNX14AJ79A

Outline

- **Background**
- Method
- Computational Results
- Conclusion

Ground Delay Programs (GDPs)

- Scheduled traffic can exceed capacity of airport to handle arrivals.
- To prevent unsafe situations, FAA will delay flights on the ground.
- FAA must select parameters such as time of affect and number of flights allowed to access resource.



Background I

- IP Models for GDP planning:
  - Many IP models proposed (e.g. Mukherjee and Hansen 2007, Ball et al. 2003, Richetta and Odoni 1993).
  - In most existing IP models the objective is to minimize weighted sum of air delays or ground delays.
  - Tend to offer little flexibility in the objectives used.

Background II

- GDP performance is not one dimensional:
  - For example, Liu and Hansen (2013) proposed 5 types of metrics designed to measure different aspects of GDP performance (capacity utilization, efficiency, predictability, equity and flexibility).
  - It is not generally possible to optimize all of these aspects simultaneously; a trade-off must be selected.

Background III

- GDP performance as a multi-objective problem:
  - Liu and Hansen (2015) proposed a method for planning GDPs whose objective combines predictability and delays.
  - Ball et al. (2017) proposed the COuNSEL mechanism, which would solicit preferences from flight operators and then select a 3-dimensional consensus vector. This vector indicated a desired tradeoff between three aspects of GDP performance (efficiency, throughput and predictability)

Goal

- Given:
  - A set of weather and traffic conditions.
  - A "target vector" specifying the desired performance.
  - Data on past GDPs/weather/traffic.
- Select:
  - A set of GDP parameters
- Goal:
  - Resulting performance should be close to desired performance.
- Proposed method is data-driven, can be used with any desired performance metrics.
- Could be used to implement a COuNSEL-like mechanism
- More generally, can support GDP decisions.

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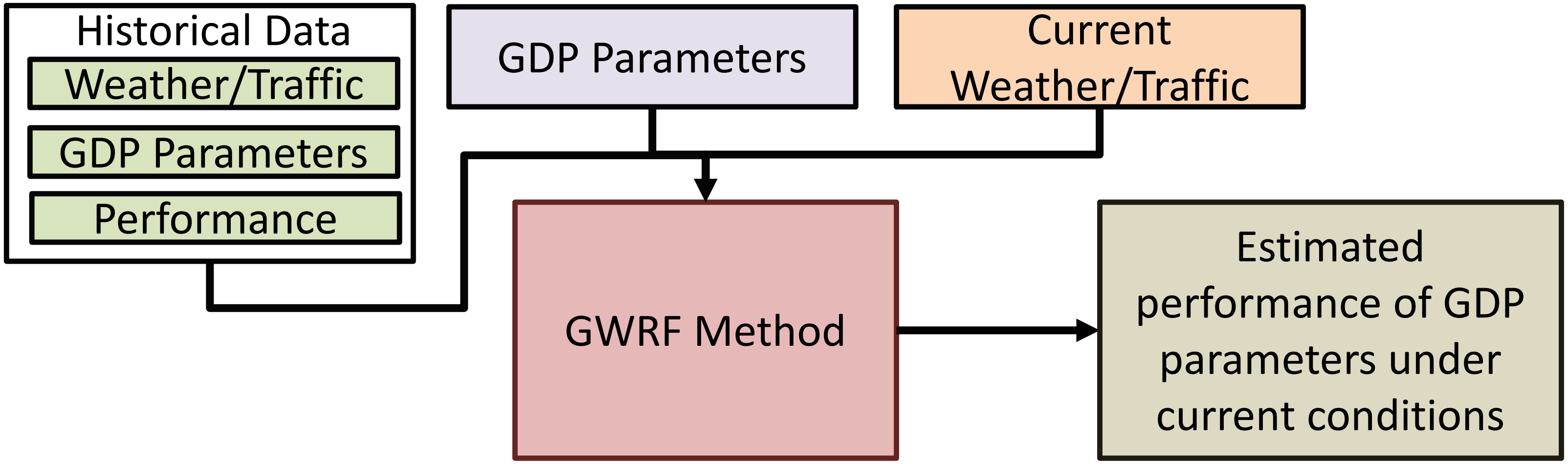
Previous Work

- Distance score between weather/traffic situations at a given airport (Gorripaty, Hansen & Podznukhov 2016)
  - Provides numerical measure of distance between pair of weather/traffic situations at an airport.
  - Features considered include convective weather near airport, weather at terminal, scheduled arrivals at airport.

Previous Work II

- GWRF Method (Estes, Lovell and Ball 2017)
  - Estimates performance of a GDP in a given set of weather and traffic conditions at a specific airport
  - Uses aforementioned distance score, converted into a similarity score.



Naïve Method I

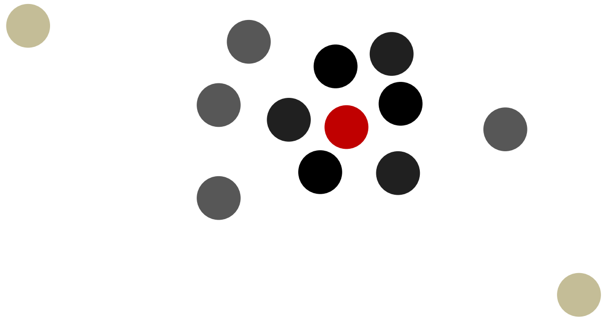
- Take each GDP that has been run in our entire dataset at the given airport.
- Use GWRF to estimate performance of that GDP under current conditions.
- Select the GDP whose estimated performance is closest to the target.

Naïve Method II

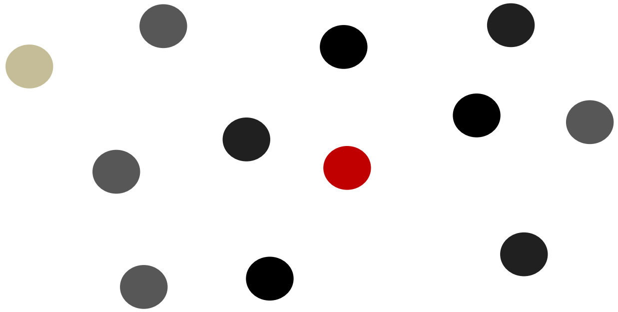
- Problem:
  - Accuracy of estimates varies with GDP parameters
  - If similar GDPs have been implemented many times in similar situations to current situation, then we expect the estimate to be accurate.
  - If not many similar GDPS have been implemented, or have only been implemented in very different situations, we expect estimate to be inaccurate.

Prediction-Weighted Similarity Score I

- Idea: develop a scoring system.
  - Higher score if estimate is based mainly on data from situations similar to current situation.
  - Lower score if estimate is based mainly on data from situations dissimilar to current situation.
  - Restrict GDPs to those with high score.



Higher Score



Lower Score

Prediction-Weighted Similarity Score II

- Definition of scoring system:
  - We have a measure of similarity between weather/traffic conditions (from distance measure)
  - Estimates are weighted sums of historical performance observations (weights depend on current situation and GDP parameters)
  - Apply same weights to similarity score between historical situation and current situation

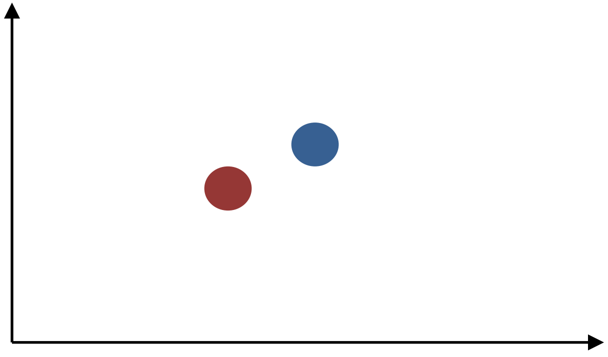
$$\hat{g}(x;z) = \sum w_i(x;z)\, y_i \qquad \hat{s}(x;z) = \sum w_i(x;z) s_i\,(z)$$

Prediction-Weighted Similarity Score III

- We can use this score to restrict our attention to GDPs whose performance estimates are well-supported by data.

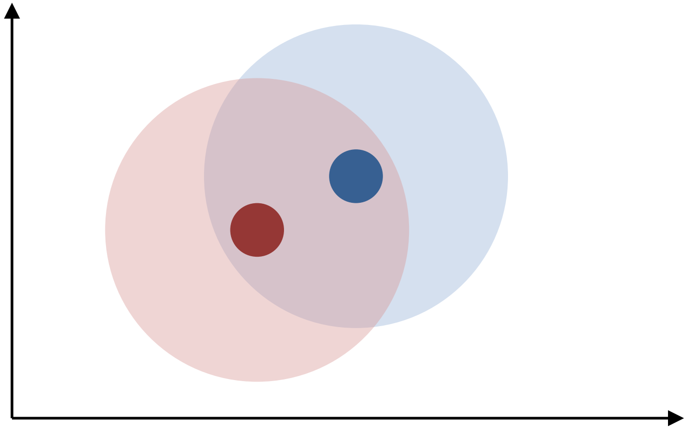
Naïve Method III

- Another downside:
  - The target vector might not be on the efficient frontier
  - It might be possible to find a set of GDP parameters that is better than the target vector in all performance measures.



Moving Closer to Efficient Frontier

- Difficulty:
  - Performance estimates are not certain.



Moving Closer to Efficient Frontier I

- Idea - adapt a ranking scheme used in evolutionary algorithms (Hughes 2000).
  - Low rank indicates that the point is probably closer to efficient frontier.
  - High rank indicates that the point is probably further from the efficient frontier.

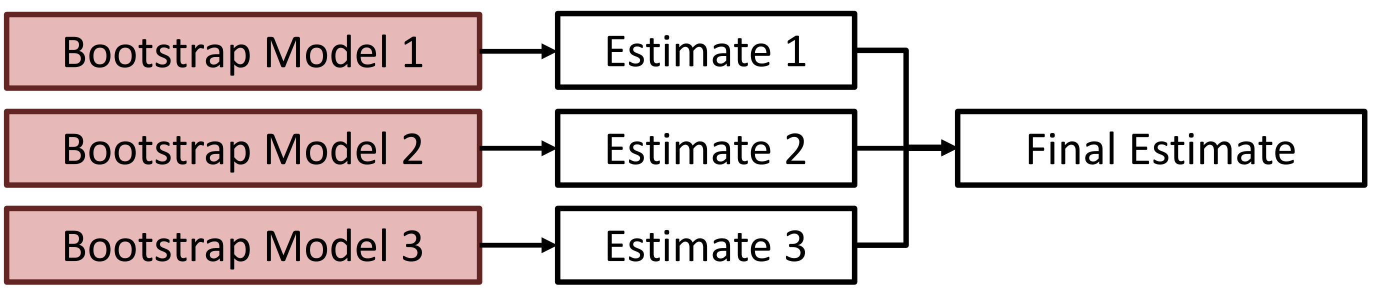
Dominance Rank I

- For each pair of GDP parameters *t* and *s*, we estimate the probability that *t* dominates *s*.
- Rank:

$$r(s;z) = \left(\sum_{t \in S} P(t \leq s; z) + \frac{1}{2} P(t \sim s; z) \right) - \frac{1}{2}$$

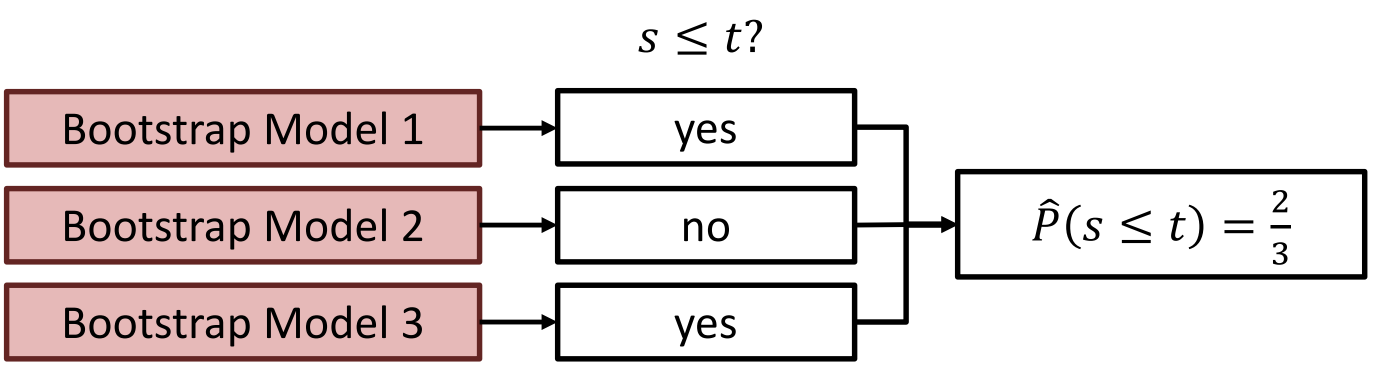
Dominance Rank II

- Probabilities are estimated as follows:
  - Performance estimation is done by bootstrapping.
  - Bootstrapping: fitting the same model multiple times with randomness introduced.
  - The estimates of these models are then averaged.



Dominance Score III

- Probabilities are estimated as follows:
  - For each models in this collection, estimate performance of parameters *s* and *t*.
  - $P(s \leq t)$ is the proportion of models in which performance of *s* dominates *t*.



Constrained Greedy Selection

- Set a threshold $s*$ for the prediction-weighted similarity score.
- Remove choices of GDP parameters with similarity score larger than $s*$.
- If all choices have similarity score larger than $s*$, then there is insufficient data to use this method.
- Form list of options that is increasing in predicted distance to target vector but have decreasing dominance rank:
  - Let x^1 be choice of GDP parameters with predicted performance closest to target vector.
  - If there is a choice of GDP parameters whose dominance rank is lower than x^k, we define x^{k+1} to be such an element whose predicted distance to the target vector is lowest.

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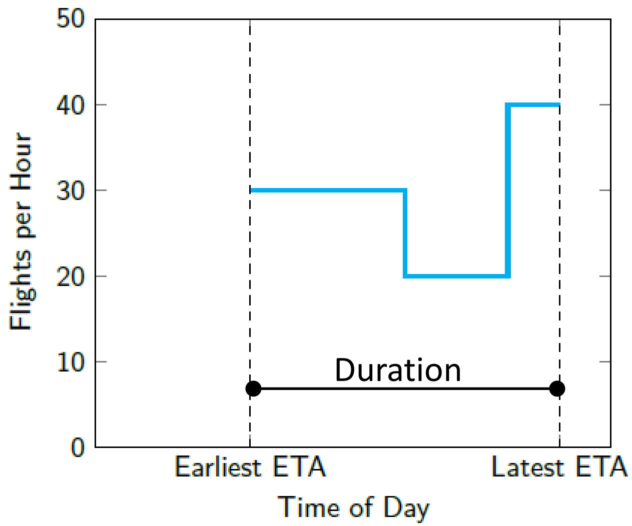
Experiment Setup

- 480 days at EWR where GDPs were run.
  - 80% training, 20% test
- Performance measures:
  - Average arrival delay
  - Holding events
  - Data source: ASPM
- We use distance scores provided by U.C. Berkeley (Gorripaty, Hansen & Podznukhov 2016)

GDP Features I

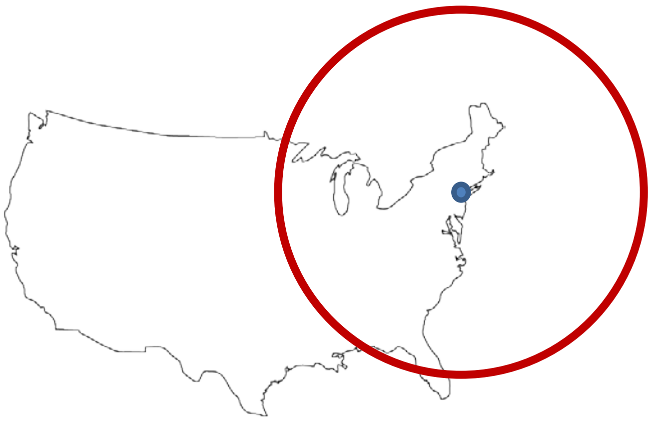
- All features reflect first planned GDP. Revisions are not included.
- File time - minutes after 4:00 a.m. local
- Start Time - minutes after 4:00 a.m. local
- Duration - minutes
- Average called rate
- Data source: NTML



GDP Features II

- Scope - number of CORE30 airports

Scope declared as radius



Scope declared by center

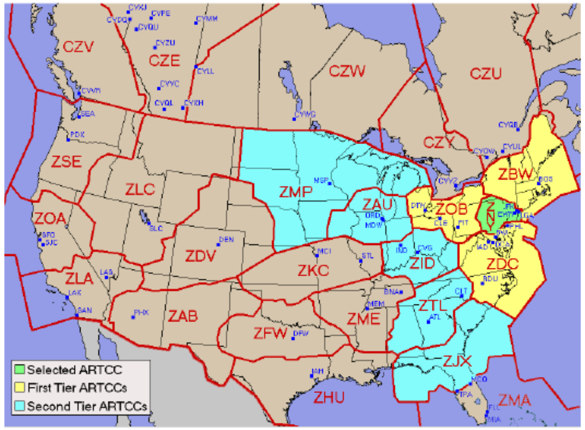
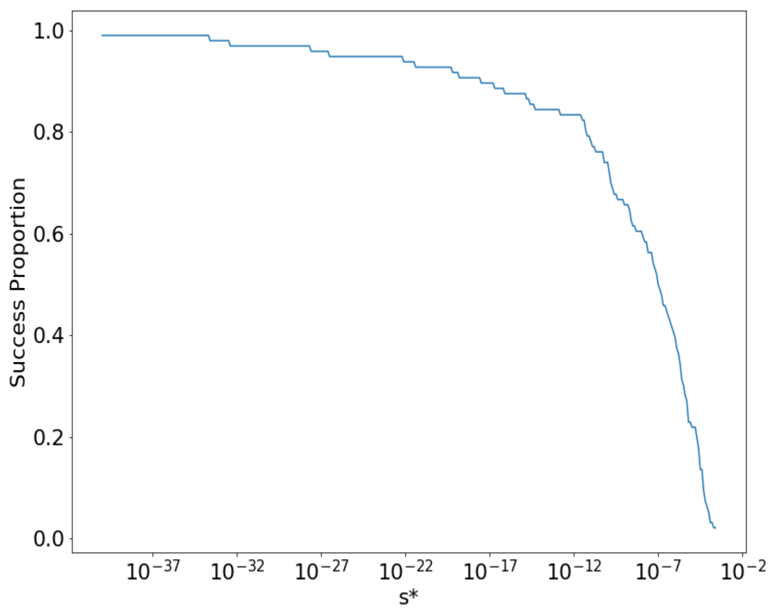


Image from FAA: http://www.fly.faa.gov/ois/tier/themap.htm

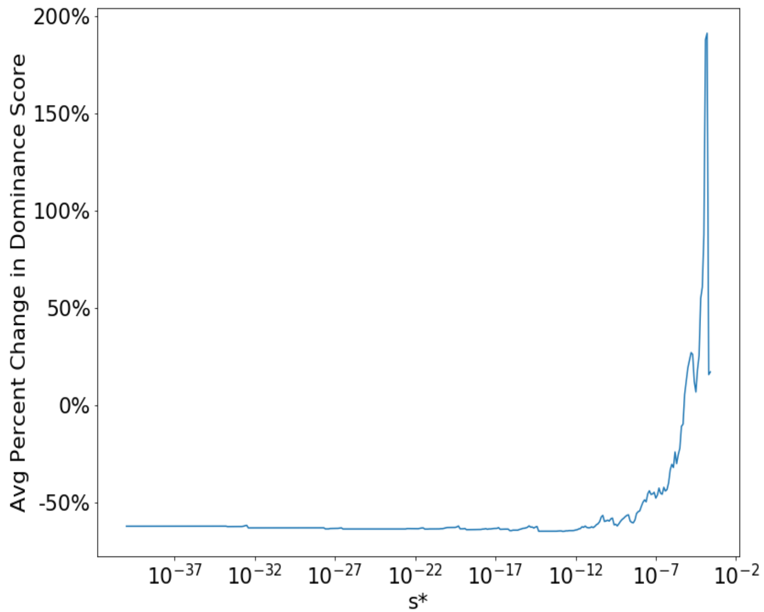
Experiment Setup II

- Performance estimation method is tuned on training set.
- For each day in test set:
  - Ran the naïve process to select a single choice of GDP parameters
  - Ran the constrained greedy selection to select a list of choices of GDP parameters

Results – Dominance score

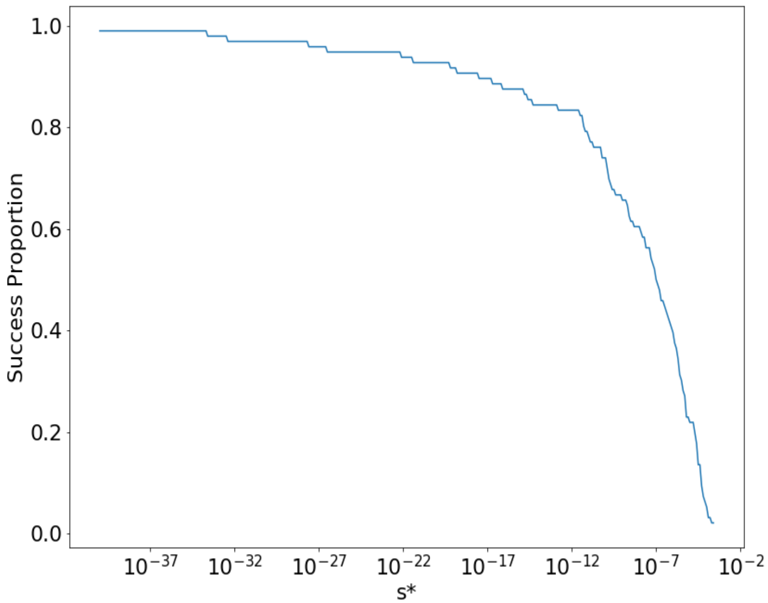


Proportion of test where proposed method returns at least one element vs. similarity threshold.



Improvement in dominance score vs. similarity threshold.

Results – Est. distance to target vector



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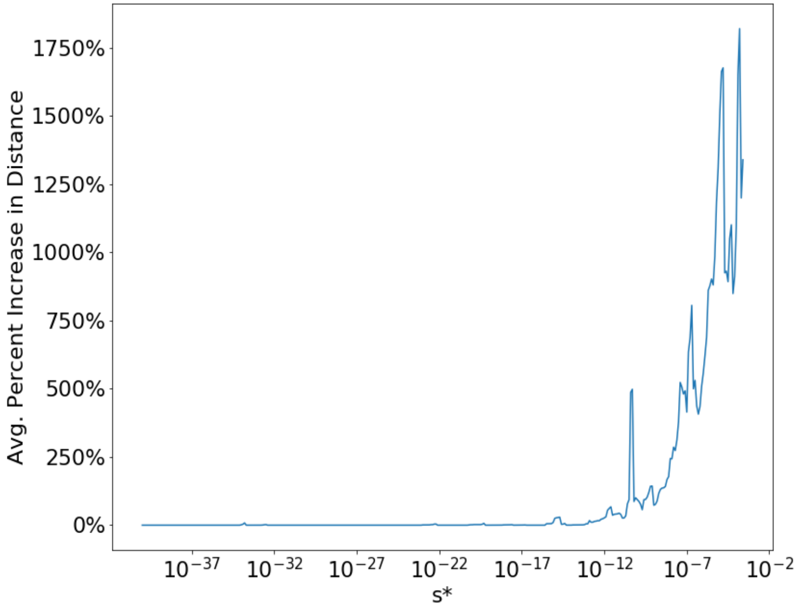
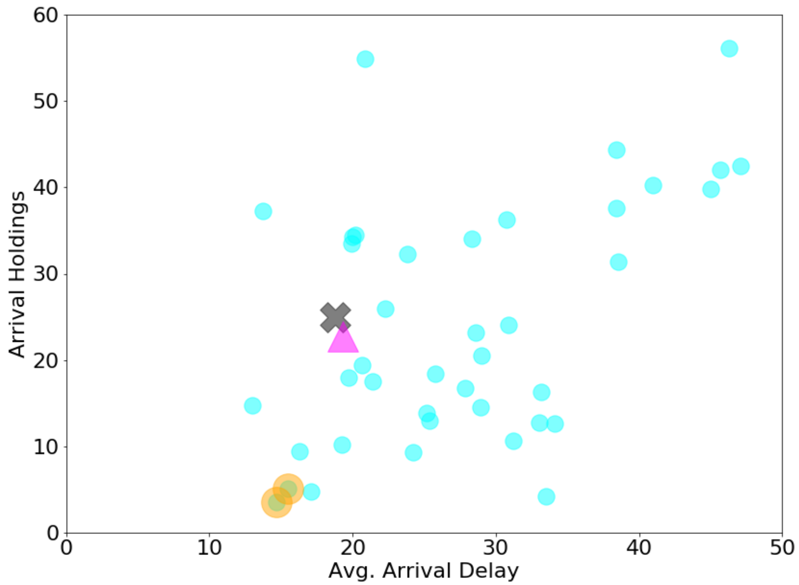


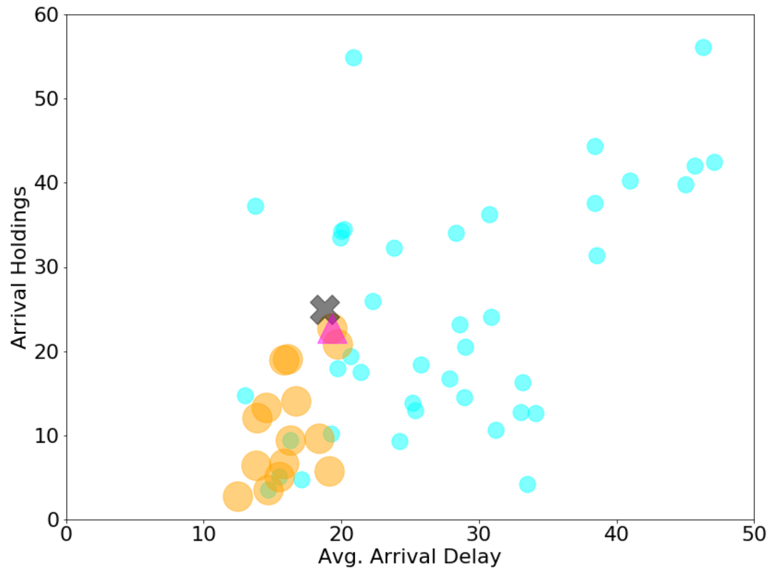
Increase in distance vs. similarity threshold.

Example

November 14, 2011



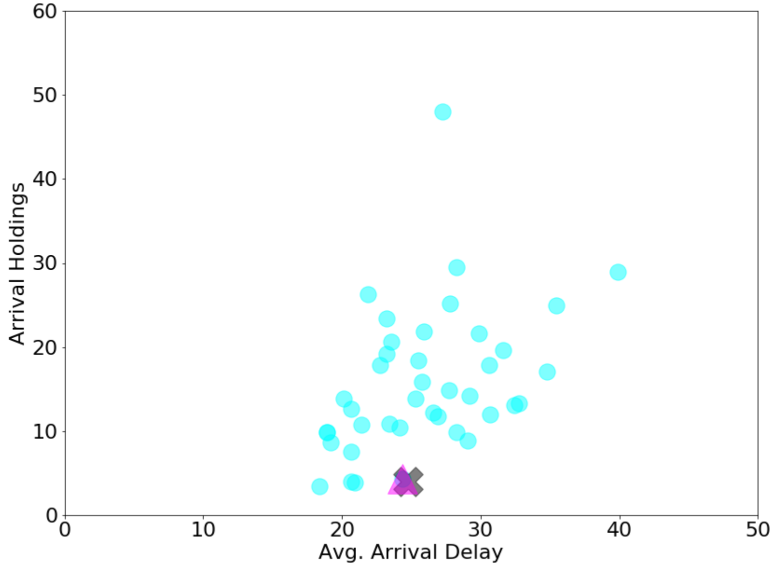
Stricter similarity threshold



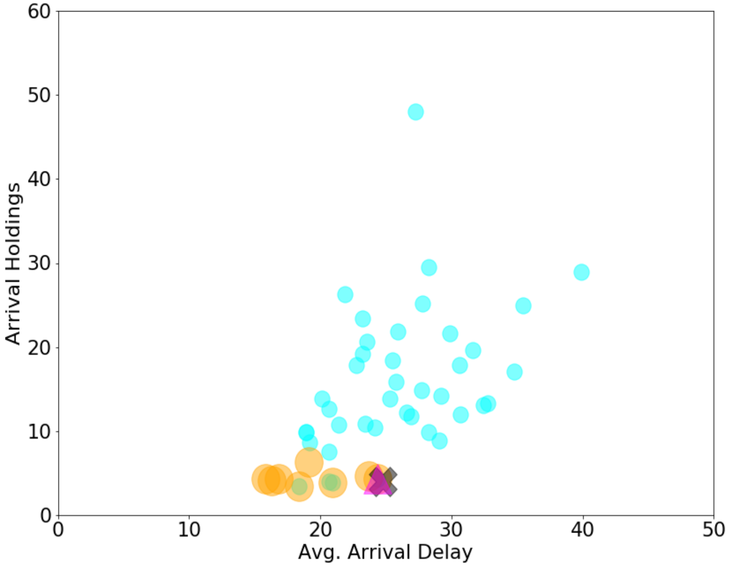
More lenient similarity threshold

Example

May 28, 2013



Stricter similarity threshold



More lenient similarity threshold

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Conclusions

- New data-driven method in support of multi-objective GDP planning
- Can be used with any type of performance measure
- Can ensure that suggested GDP options are well-supported by data
- Can identify solutions whose estimated performance is closer to efficient frontier than greedy solutions.

Further Work

- How to choose similarity threshold?
- Alternate method for when method does not provide any suggestions.
- Combining with other mechanisms (e.g. COuNSEL).
- Presenting results to decision-makers.
- Other types of traffic management initiatives