On Disruption Prediction and the Relative Cost of Disruptions

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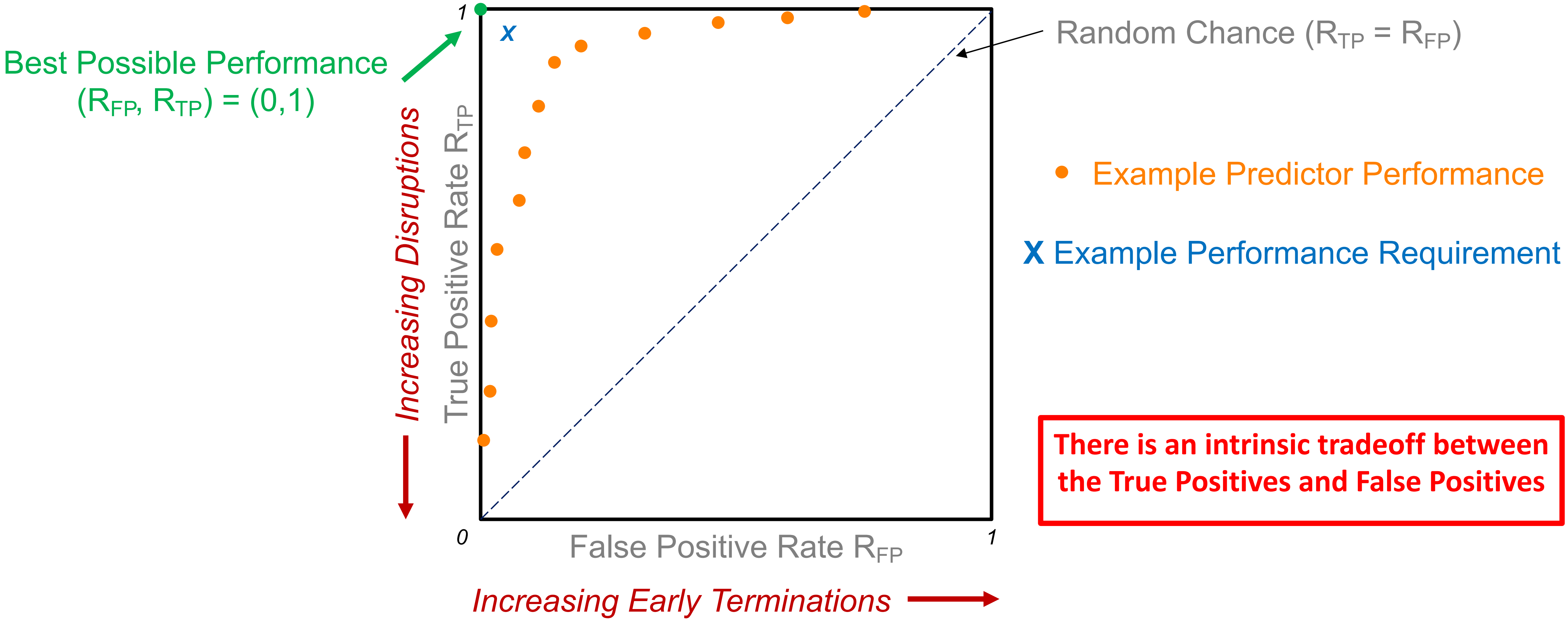
The bottom line is that we need disruption predictors to help minimize the real costs ($) associated with disruptions

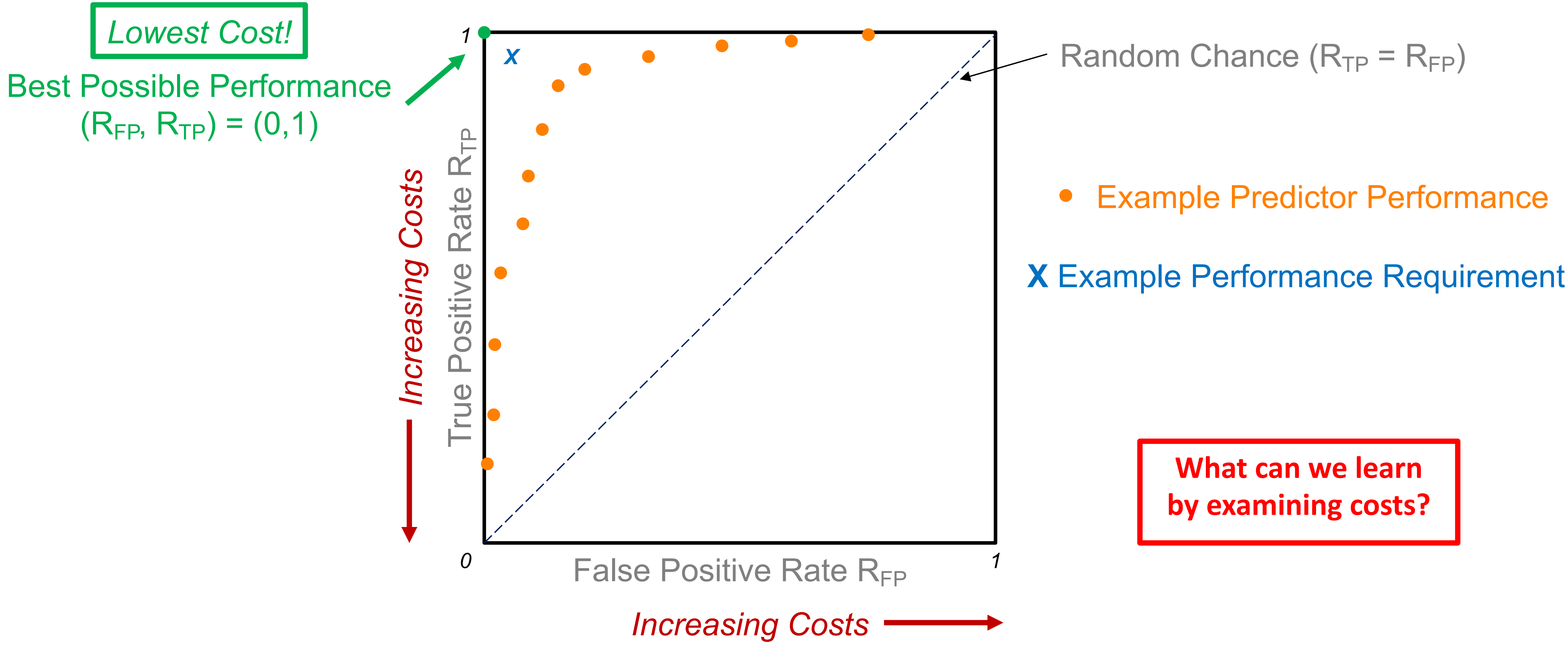
- Materials to repair/replace damaged components
- Labor to repair/replace damaged components
- Shutdown/restart of auxiliary systems
- Regulatory fines
- etc.

Disruption prediction is a 2-D optimization problem in balancing the number of disruptions *against the number of* early terminations



There is an intrinsic tradeoff between the True Positives and False Positives

There are costs associated with making the wrong prediction, so our optimization problem is really a cost minimization problem



What can we learn by examining costs?

There will be a distribution of costs associated with disruptions, beyond the baseline operating costs

Mitigation (Detection) Only

(assuming mitigation system acts on 100% of disruptions)

$$E[C_M]\, P_D$$

Expected Cost of Mitigated Disruption

Natural Disruptivity

There will be a distribution of costs associated with disruptions, beyond the baseline operating costs

Mitigation (Detection) Only

$E[C_M]\ P_D$

Mitigation + Avoidance (Prediction)

Reduced by R_{FN} — *Incurred at R_{TP}* — *Incurred at R_{FP}*

$E[C_M]\ P_D\ R_{FN} + E[C_A]\ P_D\ R_{TP} + E[C_T]\ (1 - P_D)\ R_{FP}$

Expected Cost of Avoidance Action — *Expected Cost of Early Termination*

To see when the predictor will reduce the costs associated with disruptions, we only need to compare these two cost scenarios

Mitigation (Detection) Only | **Mitigation + Avoidance (Prediction)**

$E[C_M]\,P_D \quad > \quad E[C_M]\,P_D\,R_{FN} + E[C_A]\,P_D\,R_{TP} + E[C_T]\,(1 - P_D)\,R_{FP}$

$$\frac{R_{FP}}{R_{TP}} < \left(\frac{E[C_M] - E[C_A]}{E[C_T]}\right)\left(\frac{P_D}{1 - P_D}\right)$$

Minimum performance threshold for a predictor to save costs

The Relative Cost of Disruptions

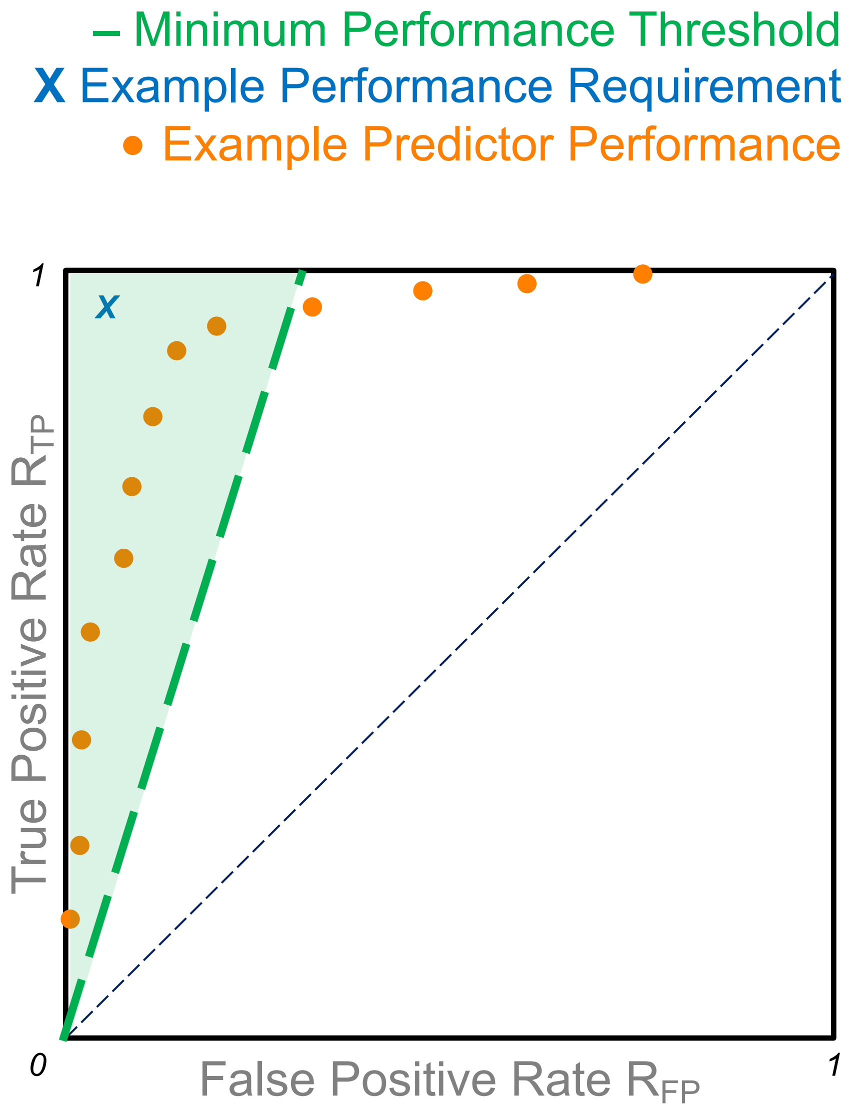
Takeaway #1
There exists a relationship between disruption prediction performance and the Relative Cost of Disruptions.

Threshold depends on the
Relative Cost of Disruptions

⇓

$$\frac{R_{FP}}{R_{TP}} < \left(\frac{E[C_M] - E[C_A]}{E[C_T]}\right)\left(\frac{P_D}{1 - P_D}\right)$$

Why should we care what the minimum performance threshold is?



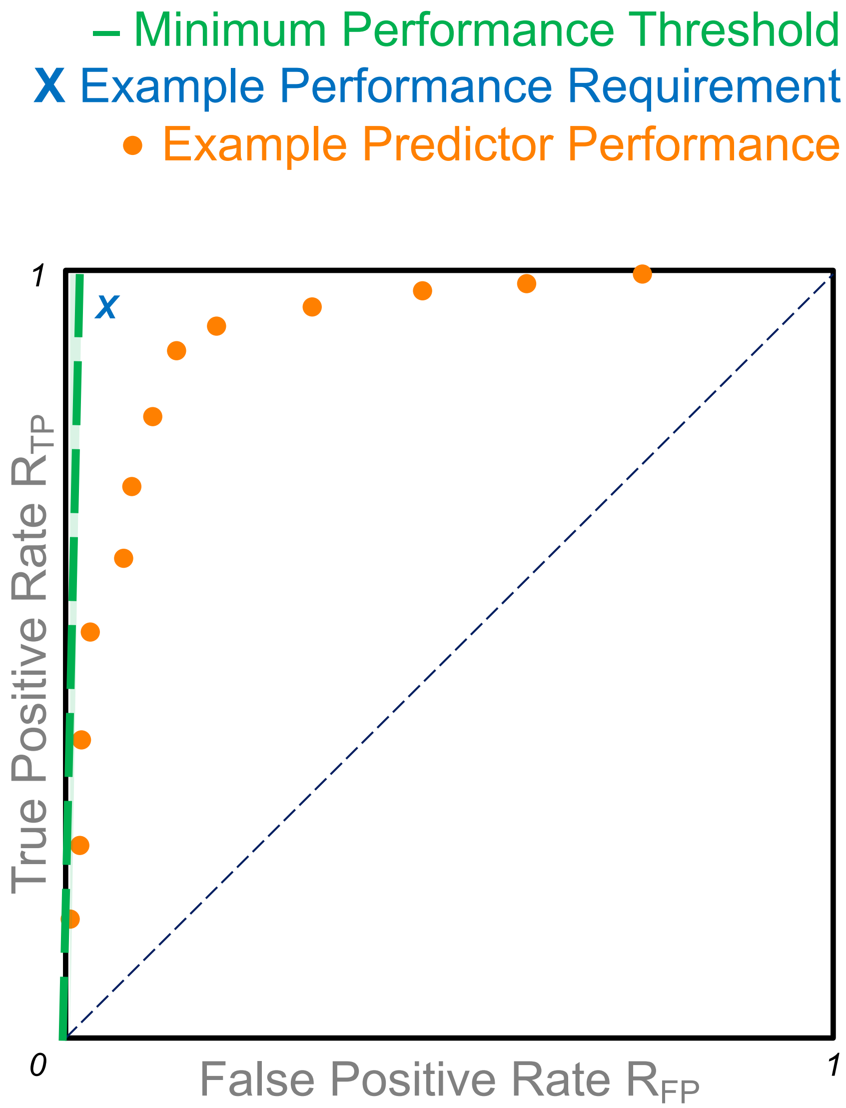
A predictor may fail to meet the desired performance requirements *but still exceed the threshold for saving costs*.

Implementing one of these is better than nothing!

Takeaway #2

The relative cost of disruptions must be considered when assessing whether a predictor should be used.

Why should we care what the minimum performance threshold is?



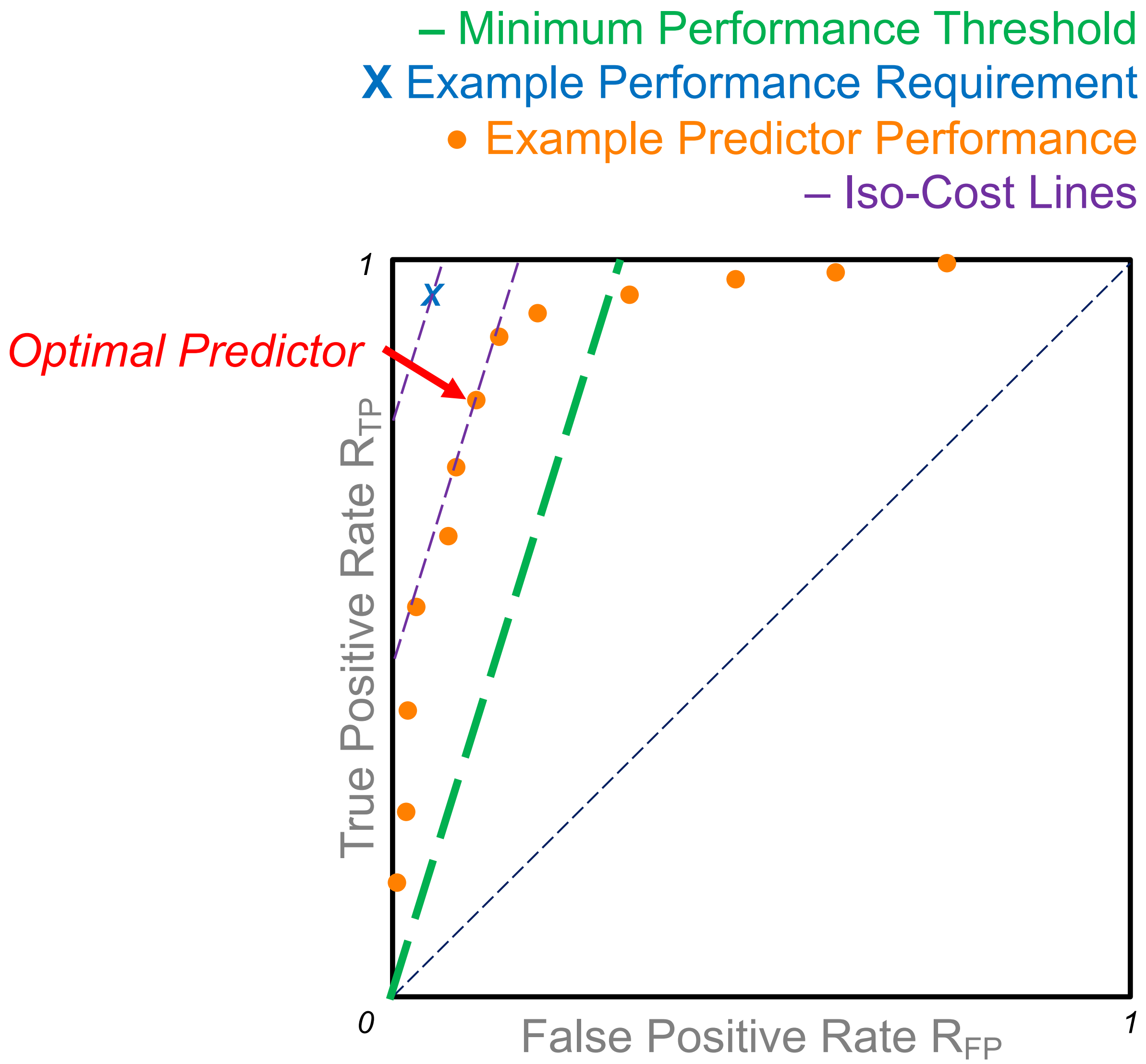
If the relative cost of disruptions is low (e.g. ineffective avoidance action), a predictor may fail to meet the minimum performance threshold.

Implementing one of these is *worse* than nothing!

Takeaway #2

The relative cost of disruptions must be considered when assessing whether a predictor should be used.

Why should we care what the minimum performance threshold is?



The iso-cost surfaces are lines parallel to the minimum performance threshold.

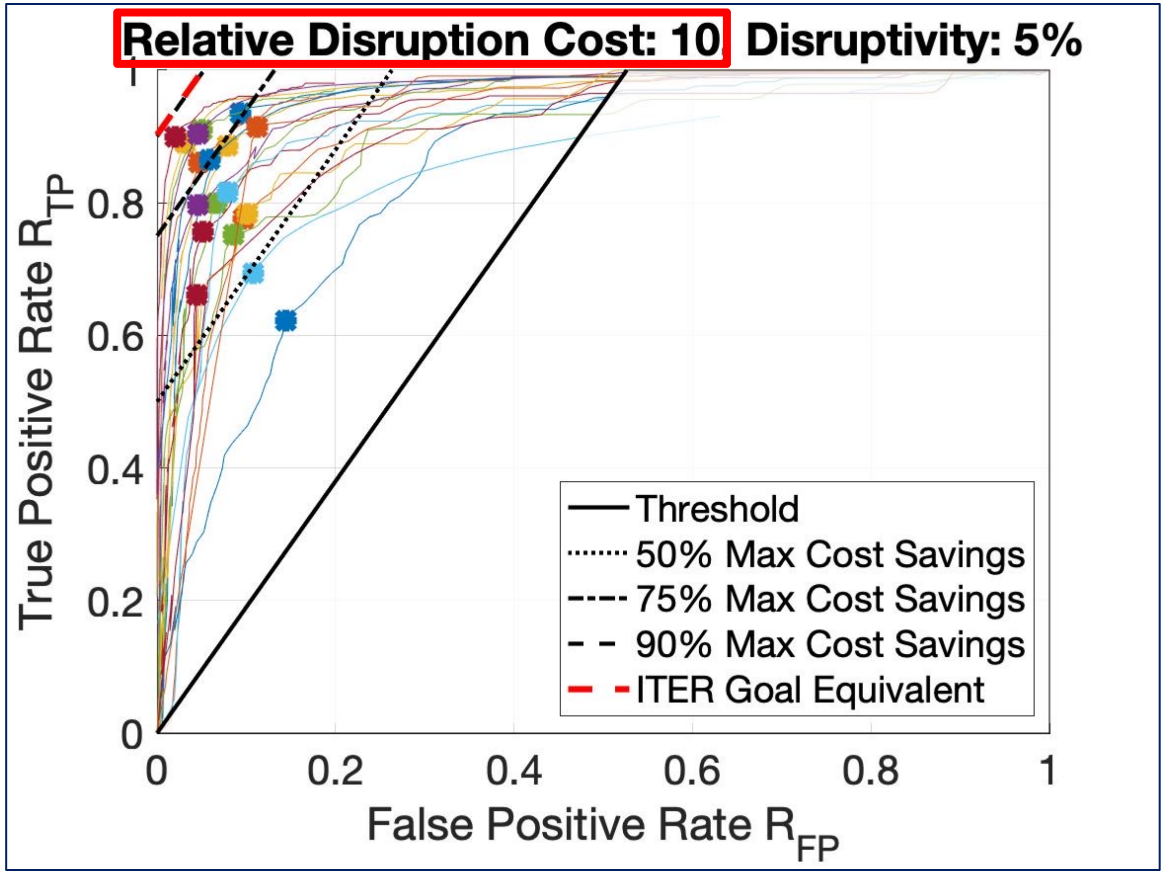
The optimal predictor will be different for different thresholds (relative costs and P_D)!

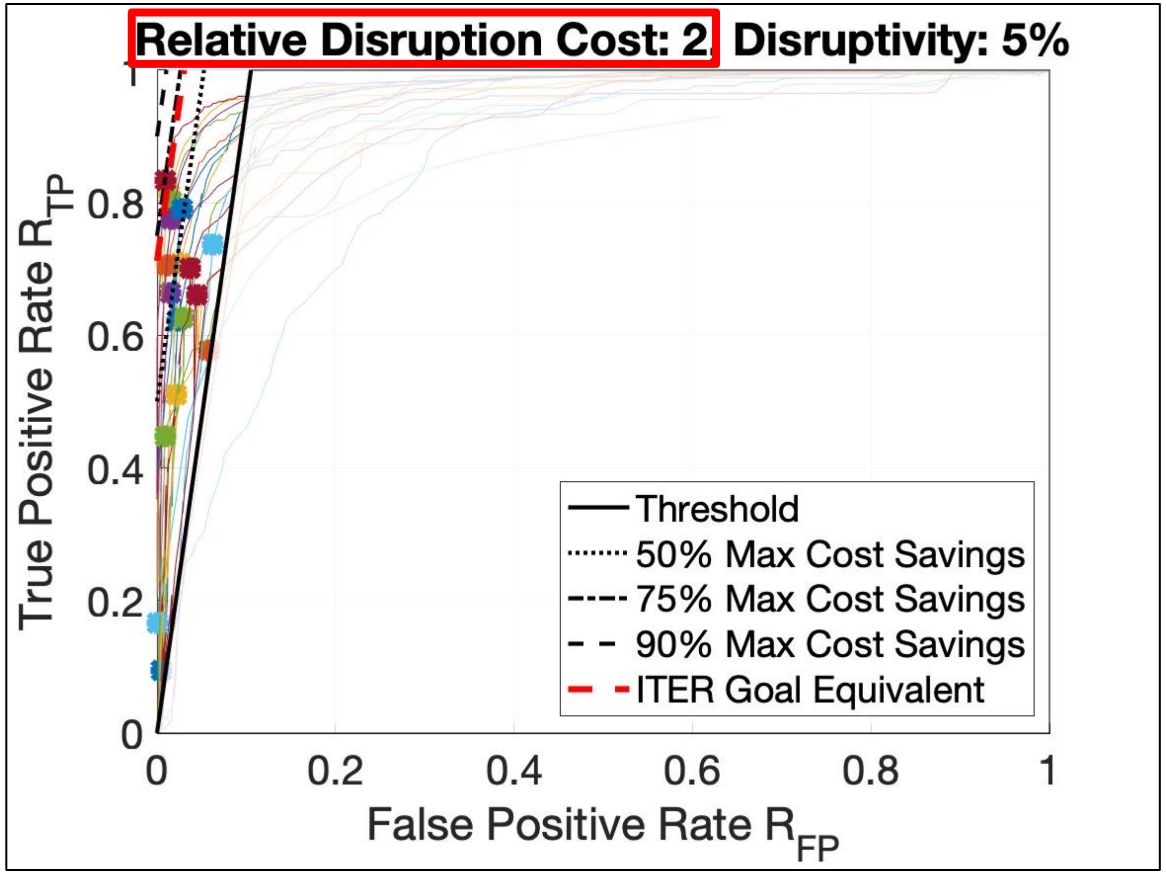
Takeaway #3

The relative cost of disruptions must be considered when identifying the best available predictor.

Applying to Examples from the Literature (References on next slide)

** Markers indicate optimal operating point on each individual ROC curve*





The Relative Cost of Disruptions *must* be considered when choosing amongst available predictors.

References

- C. Rea *et al* 2019 *Nucl. Fusion* **59** 096016
- K.J. Montes *et al* 2019 *Nucl. Fusion* **59** 096015
- Phys. Plasmas **27**, 022501 (2020); https://doi.org/10.1063/1.5125581
- J.X. Zhu *et al* 2021 *Nucl. Fusion* **61** 026007
- Yu Zhong *et al* 2021 *Plasma Phys. Control. Fusion* in press https://doi.org/10.1088/1361-6587/abfa74
- Dong, Ge, et al. *Journal of Machine Learning for Modeling and Computing* 2.1 (2021). https://doi.org/10.1615/JMachLearnModelComput.2021037052

- I used WebPlotDigitizer Version 4.3 to extract the ROC data, https://automeris.io/WebPlotDigitizer

Summary

Three Takeaways:

1. There exists a relationship between predictor performance and the Relative Cost of Disruptions

The relative cost of disruptions must be considered when:

2. assessing whether a predictor should be used, and
3. identifying the best available predictor

Suggestion:

We should dedicate some resources to assess these costs in order to properly evaluate the effectiveness of prediction tools (private companies will certainly have to do this)

Comparing Costs: The Variables

- $E[C_D]$ – Expected cost of an unmitigated Disruption
- $E[C_M]$ – Expected cost of a Mitigated disruption
- P_D – Natural disruptivity rate
- R_M – Mitigation System Reliability

- $E[C_A]$ – Expected cost of an Avoidance Action
- $E[C_T]$ – Expected cost of an early Termination
- R_{TP} – True Positive Rate of prediction
- R_{FP} – False Positive Rate of prediction
- R_{FN} – False Negative Rate of prediction (equals $1 - R_{TP}$)

- Let's assume the mitigation system detects *every* disruption and takes action (i.e. $R_M = 1$), so the cost of unmitigated disruptions doesn't clutter up the algebra…

Inputs and Outputs for Setting Prediction Requirements

Independent Parameters in the model

$$R_{TP}\left(\frac{P_D}{1-P_D}\right)\left(\frac{E[C_M]-E[C_A]}{E[C_T]}\right) > R_{FP}$$

Should be a model output!
(and will also change over time)

Engineering Constraint on Total Number of Disruptions (averaged over campaign)

This will change over time as disruptions accumulate!

Higher P_D → Can tolerate higher R_{FP} to satisfy R_{TP}

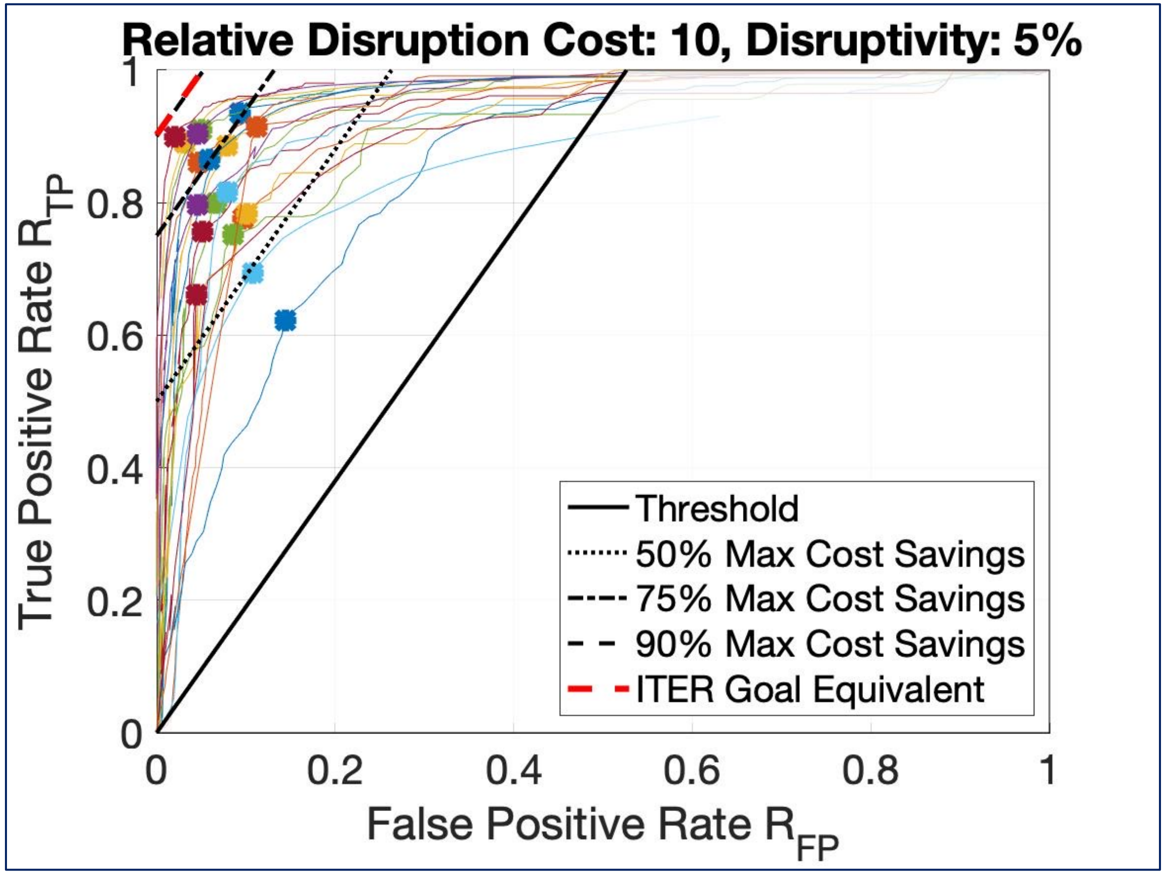
Higher R_{TP} → Can tolerate higher R_{FP} to satisfy R_{TP}

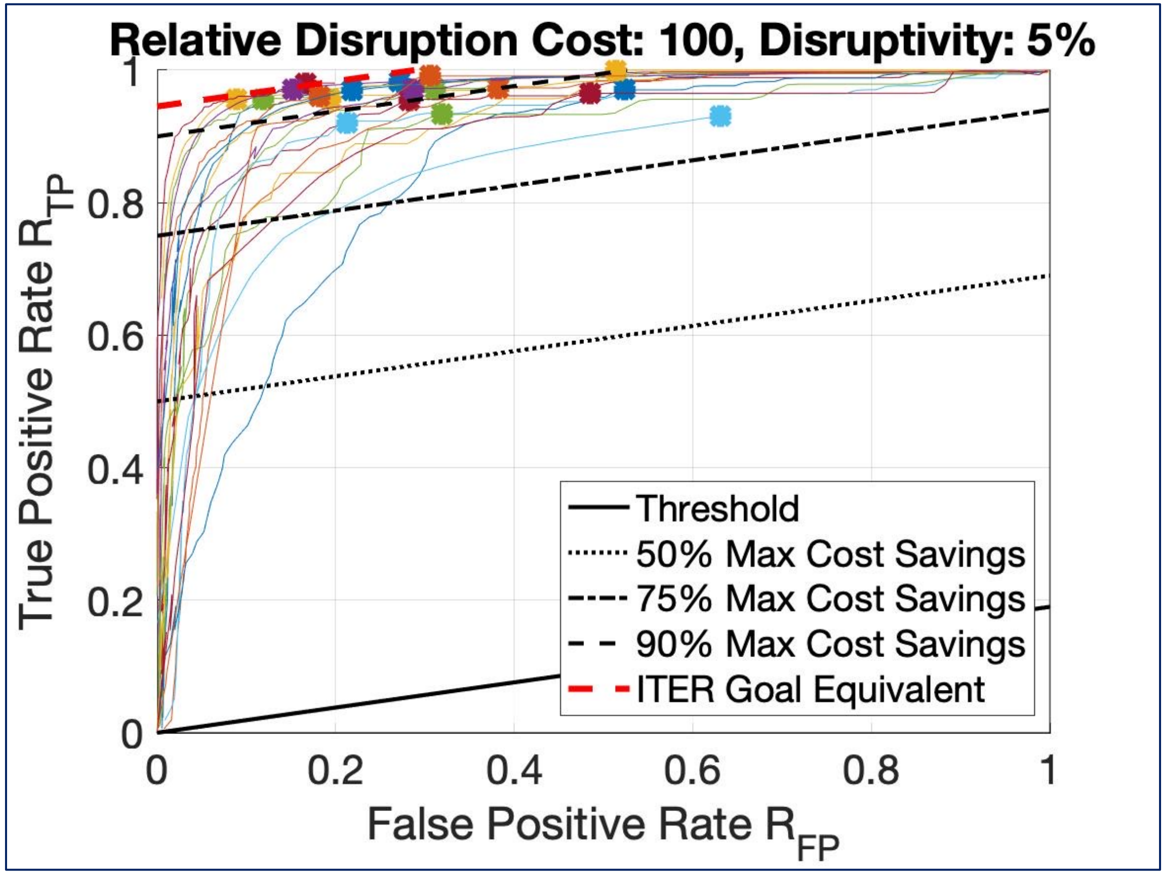
Higher $(E[C_M] – E[C_A]) / E[C_T]$ → Can tolerate higher R_{FP} to satisfy R_{TP}

The ***Relative Cost of Disruptions*** is reflected in the relationship between the False Positive and True Positive requirements

Higher Relative Cost of Disruption means larger R_{FP} can be tolerated

*Markers indicate optimal operating point on each individual ROC curve





The optimal operating point depends on the Relative Cost of Disruptions and the Disruptivity